Centre for Continuing Education

APPENDIX-1

MAXIMIZING THE GENERATION PROFIT OF RUNOFF RIVER HYDRO POWER PLANT CONSIDERING THE OPERATIONS LIMITATION i.e. WATER INFLOW FORECASTING AND LOAD FORECASTING WHILE HEDGING AGAINST CERC REGULATION (DEVIATION SETTELEMENT MECHANISM)

By

Sameer Sobti

SAP ID: 500065977

Guided By

Pankaj Kapoor

Associate Vice President (O&M)

AD Hydro Power Ltd.

A DISSERTATION REPORT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR

MBA POWER MANAGEMENT

OF

CENTRE FOR CONTINUING EDUCATION

UNIVERSITY OF PETROLEUM & ENERGY STUDIES, DEHRADUN

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AD HYDRO POWER LIMITED

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ADHPL/HR/2019-20/ 77

"Letter of Acceptance"

Pankaj Kapoor
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Subject: - Willingness for Guiding Dissertation of Mr. Sameer Sobti, SAP ID- 500065977.

Dear Sir,

Mr. Sameer Sobti is registered for MBA Power Management, with the University of Petroleum & Energy Studies, Dehradun in the 2018 batch.

I hereby give my acceptance to guide the above student through the Dissertation work Titled: **'Maximizing the generation Profit of Runoff river Hydro Power plant considering the operations limitation i.e. water Inflow Forecasting and load forecasting while Hedging against CERC Regulation (Deviation Settlement Mechanism)'**, which is the mandatory academic requirement for the award of MBA degree.

Yours Sincerely

16/07/2019
Pankaj Kapoor
Associate Vice President (O&M)
A D Hydro Power Limited

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APPENDIX-11

Acknowledgement

This is to acknowledge with thanks the help, guidance and support that I have received during the Dissertation.

I have no words to express a deep sense of gratitude to the management of AD HYDRO POWER LIMITED for giving me an opportunity to pursue my Dissertation, and in particular Mr. Pankaj Kapoor for his able guidance and support.

I must also thank Sh.Rajneesh Chauhan and Sh. Rajinder Chaudhary- Shift Incharge Operation and Scheduling ADHPL for their valuable support.

I also place on record my appreciation of the support provided by Sh. Priyavrat Sharma.

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APPENDIX-III

Declaration by the Guide

This is to certify that Mr. Sameer Sobti, a student of MBA Power Management, SAP ID 500065977 of UPES has successfully completed this dissertation report on **"MAXIMIZING THE GENERATION PROFIT OF RUNOFF RIVER HYDRO POWER PLANT CONSIDERING THE OPERATIONS LIMITATION i.e. WATER INFLOW FORECASTING ANS LOAD FORECASTING WHILE HEDGING AGAINST CERC REGULATION (DEVIATION SETTELEMENT MECHANISM)"** under my supervision.

Further, I certify, to the best of my knowledge, that the work is based on the investigation made, data collected and analysed by him and it has not been submitted in any other University or Institution for award of any degree. In my opinion it is fully adequate, in scope and utility, as a dissertation towards partial fulfilment for the award of degree of MBA Power Management.

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CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

AD Hydro 192 MW Plant IPP is basically a runoff river plant having only 2 hours of pondage for peaking purpose and sells its large energy quantum in open access through short-term bilateral PPA and in power exchange. Small unpredicted quantum is sold in intraday and in UI. Therefore, the operation of plant needs accurate water inflow forecasting for optimum generation schedule to maximize generation profit. CERC Regulation (Deviation Settlement Mechanism) imposes penalty provision on the generation entity if the generation schedule is not met or is deviated from the guidelines provided under the DSM. Therefore, the plant needs to operate within the CERC guidelines with accurate forecasting of water inflows to hedge against these financial penalties imposed by CERC DSM. AD Hydro Catchment area is glacier zone, water inflow varies on a small scale during winter as compared to summers where the water inflow varies on large scale. AD Hydro uses two strategies for operation; one for winter i.e. to store the small quantum of water in its reservoir and use it during peak load hours to earn maximum profit, as during peak hours the demand of energy is more and supply is less; where as in summers and rainy season the quantum of water is in surplus, thus proper management of water is required. Any surplus generation or paucity in generation in respect to given schedule will lead to huge penalties according to DSM thereby entailing huge financial loss to the generation entity. The main purpose of CERC behind having operational narrow frequency band is to ensure proper operation of grid and to remove monopoly, have competitive market and reduce the supply and demand gap. But from a generation entity point of view this operational strategy of CERC will have impact on generation entity's revenue. Therefore, generation entity has to work out different operational strategies.

1.2 BACKGROUND

AD Hydro power plant is a sister concern of Malana Power Company which commissioned its 86 MW plant in the year 2001 and was one of the first power plant in private sector having merchant power IPP status, selling its power in the open market. This type of strategy was very successful during that time as the supply demand gap was very broad, very few generation entities were selling power in the open market and the demand was on the higher side. Looking into the success of the above strategy, the management decided that AD Hydro Power Limited will not do any PPA and will follow the Malana Power company strategy during operation (to sell its power in open market). AD Hydro Power Plant was commissioned in 2010 and since then been selling its power in the open market. But the market scenario and the CERC DSM regulations have changed a lot since 2010. Therefore, different strategy has to be followed for operation of plant according to market scenario and CERC guidelines. From Feb. 2017 CERC has taken steps for keeping the grid frequency between 49.90 to 50.05 Hz which means that a generation entity will earn very less in UI if the schedule is not properly given as per water inflows.

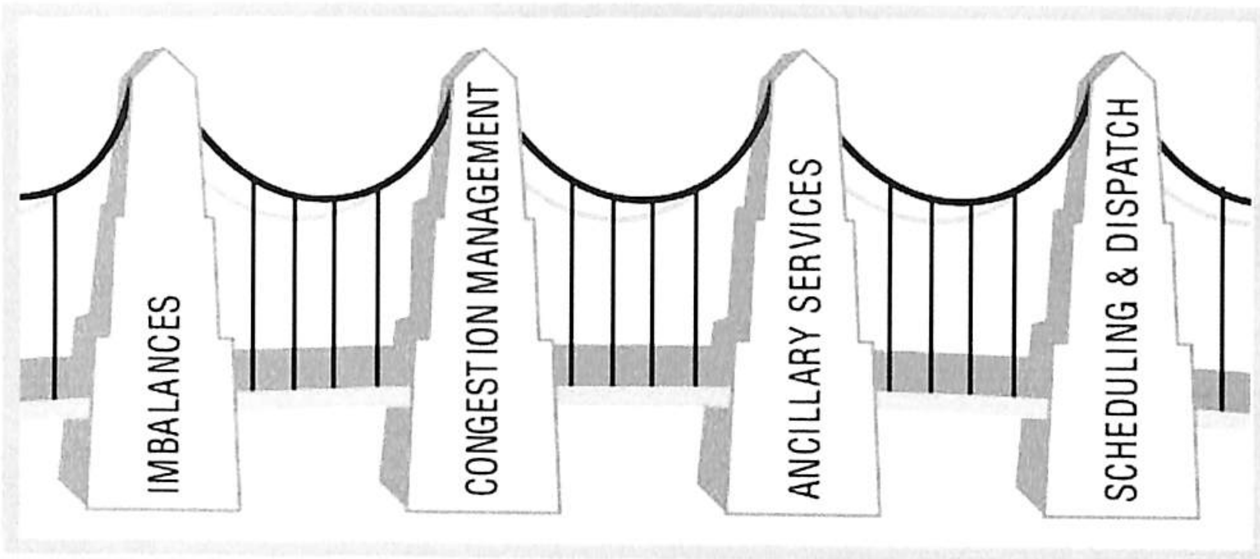
Central Electricity Regulatory Commission (CERC) vide order dated 27th April 2017 constituted an Expert Group chaired by Shri A S Bakshi, Member, CERC with representatives from CEA, POSOCO and CTU and others with the mandate to suggest further steps required to bring power system operation closer to the national reference frequency of 50 Hz and review of the principles of Deviation Settlement Mechanism (DSM). The outcome is as follows: -

a. Review the experience of grid operation in India.
b. Review international experience and practices on grid operation including standards/requirement of reference frequency.
c. Review the existing operational band of frequency with due regard to the need for safe, secure and reliable operation of the grid.
d. Review the principles of Deviation Settlement Mechanism (DSM) rates, including their linkage with frequency, in the light of the emerging market realities.

Any power system needs to balance the generation and consumption of energy over multiple time frames from seconds, hours, days and even years ahead. There is always deviation in actual generation from scheduled generation and actual drawal from scheduled drawal. There will always be differences between the contracted volumes and the actual metered volumes. Thus, to handle these differences (or imbalances) in real time, there is a need for imbalance handling mechanism.

Sally Hunt in her book titled" Making Competition Work in Electricity"[1], mentioned that the four pillars of good electricity market design are Imbalances, Congestion management, Ancillary services and Scheduling and Despatch as depicted in the figure below. All of these must work together for a vibrant electricity market.

Pillars of Electricity Market Design



CERC introduced the Availability Based Tariff (ABT) Mechanism vide its Order dated January 4, 2000 at inter-State level [2]. The ABT Mechanism was implemented in different regions in a phased manner in the period from 2002-2003. ABT Mechanism was implemented in Western Region and Northern Region in 2002 and in Southern Region, Eastern Region and North-Eastern Region in 2003.

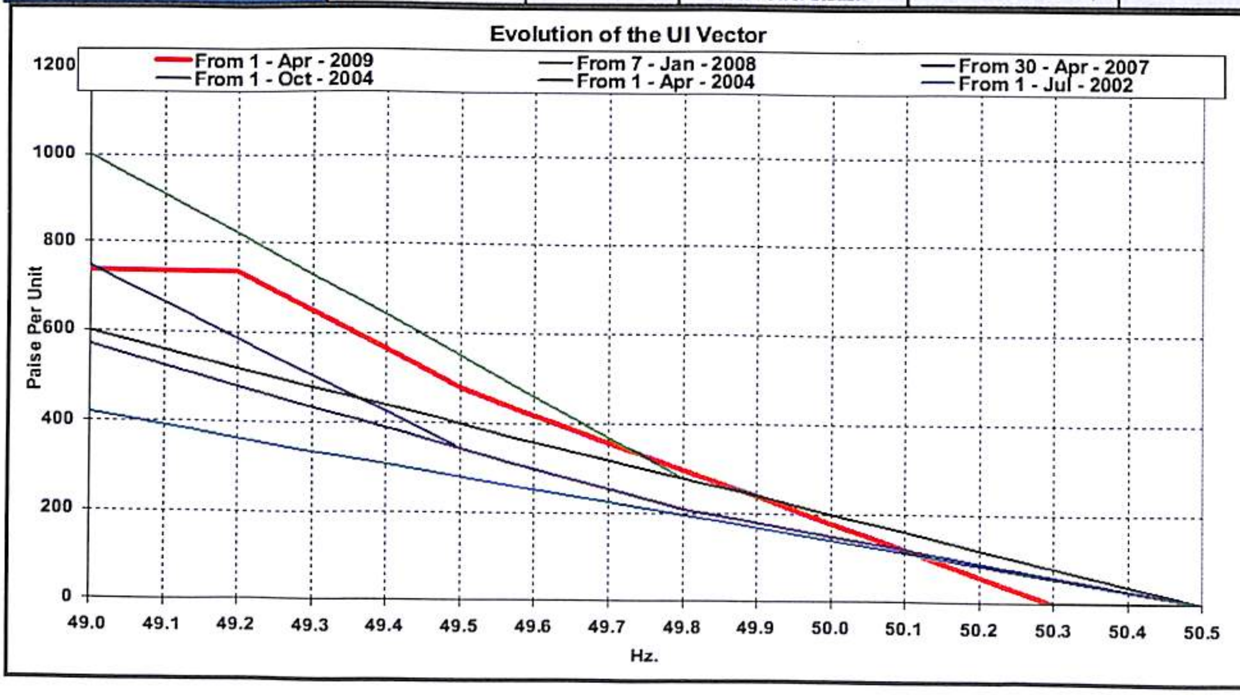
The imbalance handling mechanism has been in operation at the inter-state level for nearly 15 years. The evolution of Deviation Price (erstwhile Unscheduled Interchange (UI)) Vector over the years is tabulated in the Table-1 below.

A coordinated multilateral scheduling model has been adopted in India. Schedules can be revised and the entities are allowed to deviate within specified limits from the schedule. Large quantum of deviations from scheduled power flows may lead to uncertainties in power flow and consequential power system security issues. The deviations are settled as per the UI/DSM Rate Vector administered by CERC.

Table-1

Evolution of Deviation Price (erstwhile UI) Vector

Period	Operational Frequency Band	Ceiling Rate (paise/kWh)	Benchmarking of Ceiling Rate	Slope (paise/kWh)	Step size
1st July 2002 – 31st March 2004	49.0 Hz – 50.5 Hz	420	DG set	5.6	0.02 Hz
1st April 2004 – 30th Sept 2004	49.0 Hz – 50.5 Hz	600	DG set	8	
1st October 2004 – 29th April 2007	49.0 Hz – 50.5 Hz	570	DG set	9	
30th April 2007- 6th Jan 2008	49.0 Hz – 50.5 Hz	745	Domestic Naphtha (Liquid Fuel)	6 (50.5-49.8) 9 (49.8-49.5) 16 (49.5-49.0)	
7th Jan 2008 – 31st March 2009	49.0 Hz – 50.5 Hz	1000	Combined cycle plants -Naphtha/RLNG	8 (50.5-49.8) 18 (49.8-49.0)	
1st April 2009 – 2nd May 2010	49.2 Hz – 50.3 Hz	735	RLNG based generating station with variation in fuel prices of around 5%	12 (50.3-49.8) 17 (49.8-49.2)	
3rd May 2010 to 16th Sep 2012	49.5 Hz – 50.2 Hz	873	Gas/liquid fuel based thermal generating stations of NTPC & NEEPCO	15.5(50.2-49.7) 47 (49.7-49.5)	
17th Sep 2012 to 16th Feb 2014	49.7 Hz – 50.2 Hz	900	Highest cost of generation is 896.02 Paise/kWh @Auraiya CCGT Station	16.5 (50.2-50.0) 28.5 (50.0-49.8) 28.12 (49.8-49.5)	
17th Feb 2014 onwards	49.90 Hz - 50.05 Hz	824	Highest cost of generation is 8.24 Rs/kWh @ Auraiya Gas Power Station	20.84 (49.70 - 50.00) 35.60 (50.01 - 50.05)	0.01 Hz



Deviation Settlement Mechanism in India came into force with effect from 17th February, 2014. The salient features are as follows:

- Operational Frequency Band has been tightened to 49.90 - 50.05 Hz.
- Step size changed from 0.02 Hz to 0.01 Hz.

- The charges for deviation for each 0.01 Hz step is 35.60 Paisa/kWh in the frequency range of 50.05 - 50.00 Hz, and 20.84 Paisa/kWh in frequency range 'below 50 Hz' to 'below 49.70 Hz' and as per the methodology specified in the Regulations.
- The volume of deviation from scheduled to actual injection/drawl is 150MW or of 12% of the schedule, whichever is low.
- Continuous over drawl / under drawl has also been prohibited.
- Within 12 time blocks, the polarity of deviation should be reversed (in case of over drawl to under drawl and vice versa).
- Generating stations regulated by CERC using coal / lignite / APM gas have cap rate of 303.04 p / unit irrespective of frequency.
- There are no charges for Under-drawl or Over-injection (except infirm generation) in excess of 150MW or 12% of schedule, whichever is less in a time block.
- Additional Charges for Deviation for Over-drawl by any buyer or Under-injection by any seller has been stipulate by the CERC Regulations.
- Limit on Deviation Volume has been imposed.
    - Over-drawl by Buyer, Under-injection by Seller below 49.70 Hz and Over-injection by Seller at 50.10 Hz & above is not permitted.
    - Deviation of only 12 % of the Schedule or 150 MW, whichever is less has been allowed for Over-drawl by Buyer, Under-drawl by buyer, Under-injection by Seller at 49.70 Hz & above and Over-injection by Seller below 50 Hz.
    - Any infirm injection of power by a generating station prior to COD of a unit during testing and commissioning activities shall be exempted from the volume limit specified above for a period not exceeding 6 months or the extended time allowed by the Commission in accordance with Connectivity Regulations.

In case of start-up drawl power exemption from volume limits for frequency greater than or equal to 49.70 Hz has been allowed.

The limits for over injection and under injection are mentioned below in the 3rd amendment of CREC DSM (Amendment of Regulation 5 of the Principal Regulations).

1 Clause (iii) of Proviso to Regulation 5(1) of the Principal Regulations shall be substituted as under:

"The charges for the deviation for under-drawal by the buyer (except Renewable Rich State) in a time block in excess of 12% of the schedule or 150 MW, whichever is less, shall be zero.

Provided that in case schedule of a buyer (except Renewable Rich State) in a time block is less than or equal to 400 MW, the charges for the deviation for the under-drawal in excess of 48 MW shall be zero.

Provided further that Deviation for the under-drawal by the Renewable Rich State in excess of the limits specified in Annexure-III shall be zero."

2 Clause (iv) of Proviso to Regulation 5(1) of the Principal Regulations shall be substituted as under:

"The charges for the deviation for the over-injection by the seller (except Renewable Rich State) in a time block in excess of 12% of the schedule or 150 MW, whichever is less, shall be zero, except in case of injection of infirm power, which shall be governed by clause (5) of this regulation:

Provided that in case schedule of a seller (except Renewable Rich State) in a time block is less than or equal to 400 MW, the charges for the deviation for the over-injection in excess of 48 MW shall be zero:

Provided further that charges for deviation for over-injection by a Renewable Rich State in a time block in excess of limits as specified in Annexure-III shall be zero.

Provided also that charges for deviation for wind and solar generators which are regional entities, shall be governed by sub-clauses (v) to (vii) of this regulation.

1.3 PURPOSE OF THE STUDY

Operation of runoff river type hydro plant possess many operational challenges as there is no provision of large storage of surplus water, therefore, accurate scheduling is required according to the water inflow. The water inflows prediction is not an easy task as water forecasting requires data analysis from primary as well from secondary sources. Also the generator needs to comply with CERC guidelines. If the generation schedule given is deviated due to wrong water forecasting then penalty is imposed on the generators as per DSM which will result in loss of revenue for the company. Similarly load forecasting is also considered as a problem due to demand curve varying throughout the day on daily basis and depends on many factors such as weather, seasons etc. The demand curve decides the unit price of energy sold in Power Exchange. Therefore, the water inflow has to overlap the demand curve in such a way that it results in maximum profit. The generation entity has to work out different operational strategies. That involves -

1. Proper forecasting of load and inflow water.
2. Optimal scheduling while hedging against DSM penalties.

1.4 RESEARCH HYPOTHYSIS

Maximum operation profit for power generating entity is function of water inflow forecasting, load forecasting and preparing schedule quantum according to demand curve. Also avoiding penalties DSM regulations.

1. Optimal profit can be achieved by proper scheduling
2. Optimal profit can be achieved by proper forecasting of water inflows
3. CERC DSM Penalties can be avoided by proper management of water.

CHAPTER 2

LITERATURE REVIEW

In India as per the current scenario for Power market the monopoly of power generation companies has vanished after the implementation of CERC regulation. The energy is sold as a commodity in a competitive power trading market, where the purchaser has a choice to purchase the electricity from different sellers and vice versa. Energy in Indian market can be sold through long term PPA, Short Term PPA, Power Exchange, intraday and small quantum in UI.

Under sec 178 CERC 2003. CERC dated 6th Jan 2014 No.L-1/132/2013/CERC framed the DSM (Deviation settlement mechanism) and related matters to eliminate the monopoly of generators and gaming system to narrow the supply demand gap. DSM also provides for incentives and penalties for generators on deviations to make grid more reliable. The latest DSM guidelines is the 5th amendment dated 18th April, 2019 currently in operation which all the generators have to comply with.

2.1 REVIEW AREA BROAD.

Scheduling & water forecasting Literature:

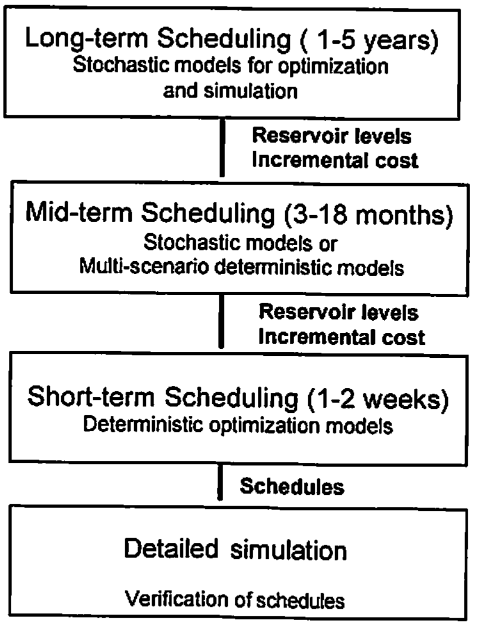
Martin Belsnes, Terje Gjengedal1 & Olav Bjarte Fosso, Statkraft Energi AS, Lilleakerveien 6, N-0216 Oslo, Norway

Norwegian University of Science and Technology, Trondheim, Norway.

Scheduling of hydro dominated power systems is a challenging task that should take into account all relevant information ranging from short-term to long-term time horizon. For multi-year reservoirs a scheduling horizon of up to 5 years may be required for deciding the seasonal and multi-year operations. At the same time short-term elements such as start/stop and ramping of units, short term regulations and constraints on changing the water discharges from one hour to the next, should also be included.

Ideally, both the long–term and the short-term elements should have been integrated into one large optimization model, and the optimal decision should then be calculated taking into account all these effects simultaneously. However, due to the complexity of the problem such an overall methodology does not presently exist.

The scheduling process is, therefore, divided into a number of stages, ranging from long term scheduling to short term scheduling. The long term stage takes into account multi-year decisions. The short-term and real-term scheduling takes into account the daily and hourly constraints, spot marked bidding and all relevant short-term information. In order to ensure Consistency between the different levels, results from one scheduling level is used as input to the consecutive levels



Scheduling problem decomposition

The long-term scheduling models are typically stochastic models for calculating an optimal strategy for hydro system operation. For the power producers, a long-term model may either be used for scheduling own resources in a market environment, or to do price forecasting or doing both simultaneously. In the latter case, the complete system must be modeled.

The long-term models have to use aggregated reservoir models and do not provide boundary conditions for the short-term models with sufficient accuracy.

The medium term model may be seen as a link between the long and the short term scheduling models, a means of transforming results from the long term scheduling process to a form suitable for giving correct impulses to the short term scheduling process. The medium term model has a planning horizon of typically one year and the same time increment (one week) and system model as the long term model. However, the medium-term models should have an approximate similar topology description in the optimization procedure as the short-term model to be able to supply suitable boundary conditions.

Short term scheduling is often solved as a deterministic problem, but may also include uncertainty. Short-term models use short time increments and support a more detailed system model than in the previous models. On all levels, the power producers will try to maximize their profit while taking the risk into account.

The goal of short-term scheduling is to minimize the cost for covering a load obligation or maximizing income if a market is present. This optimization must be performed while implementing the strategy from the long-term planning. The result is optimal generation schedules for the generation assets in the system. The challenge is in either case, minimize cost or maximize income, to find the exact balance between efficiency of the hydropower plants and the resource cost including the optimal unit commitment sequence. This is basically a nonlinear problem with state dependency introduced by the relation between the reservoir levels and the decision variables. An example is the efficiency of the plant, which depends on various dependable variable like net plant head, which depends on reservoir volume, which again depends on the value of the decision variables the model which we are searching for.

- Generally, there is great variation in the characteristics of different types of hydro systems. In many systems, there are often varying storage capacities along the water course. Some hydro power plants are connected to big reservoirs which give flexibility, while other systems are more run-of-the-river type. In the latter one, non-linear time delays may be a challenge.
- The resources available in a reservoir depend on upstream discharge decisions.
- Generally, all units have a strong non-linear relation between discharge and power production due to non-linear efficiency curves. The shape of these curves also depends on the net plant head that again depends on the discharge.
- Each power production plant may have several units hydraulically coupled, where the optimal production level on one unit depends on the production on the others. The selection of unit combinations is not trivial in such a case even if one single time step is considered.
- The expenses associated with start/stop are important for the overall optimal solution. Discrete decisions must be included. In some cases, it may also be desirable to include

constraints on minimum up times. Such dynamic constraints complicate the decision process significantly.

- Hydro power plants may discharge from more than one reservoir simultaneously. The discharge from each Reservoir may depend on gate positions, but will generally show a nonlinear behavior due to quadratic losses and changing upstream reservoir level.
- Tunnels between reservoirs make refilling of reservoirs strongly non-linear.
- Ramping constraints on discharge and reservoir level changes may be present either between single or multiple time steps.
- Overflow descriptions are non-linear relations.
- Finally, many of the operating constraints are simply not suited for mathematical modelling. Examples may be operating agreements and other constraints that are difficult to model. Without a proper handling of such constraints, it may be difficult to get acceptance for the proposed schedules, and they may even be infeasible.

CERC Literature:

The Central Electricity Regulatory Commission notified the Central Electricity Regulatory Commission (Deviation Settlement Mechanism and related matters) Regulations, 2014 in January 2014, which were thereafter amended via the first amendment (notified in December 2014), the second amendment (notified in August 2015) and the third amendment (notified in May, 2016). The objective of these regulations is to "maintain grid discipline and grid security as envisaged under the Grid Code through the commercial mechanism for Deviation Settlement through drawal and injection of electricity by the users of the grid".

Analysis of the grid frequency, which is a primary indicator of the health of the grid, suggests that the frequency has stabilized closer to 50 Hz over time. Progressive tightening of the frequency band, volume limits on deviation along with other deterrents and enforcement of DSM regulations have contributed to this improvement in frequency profile

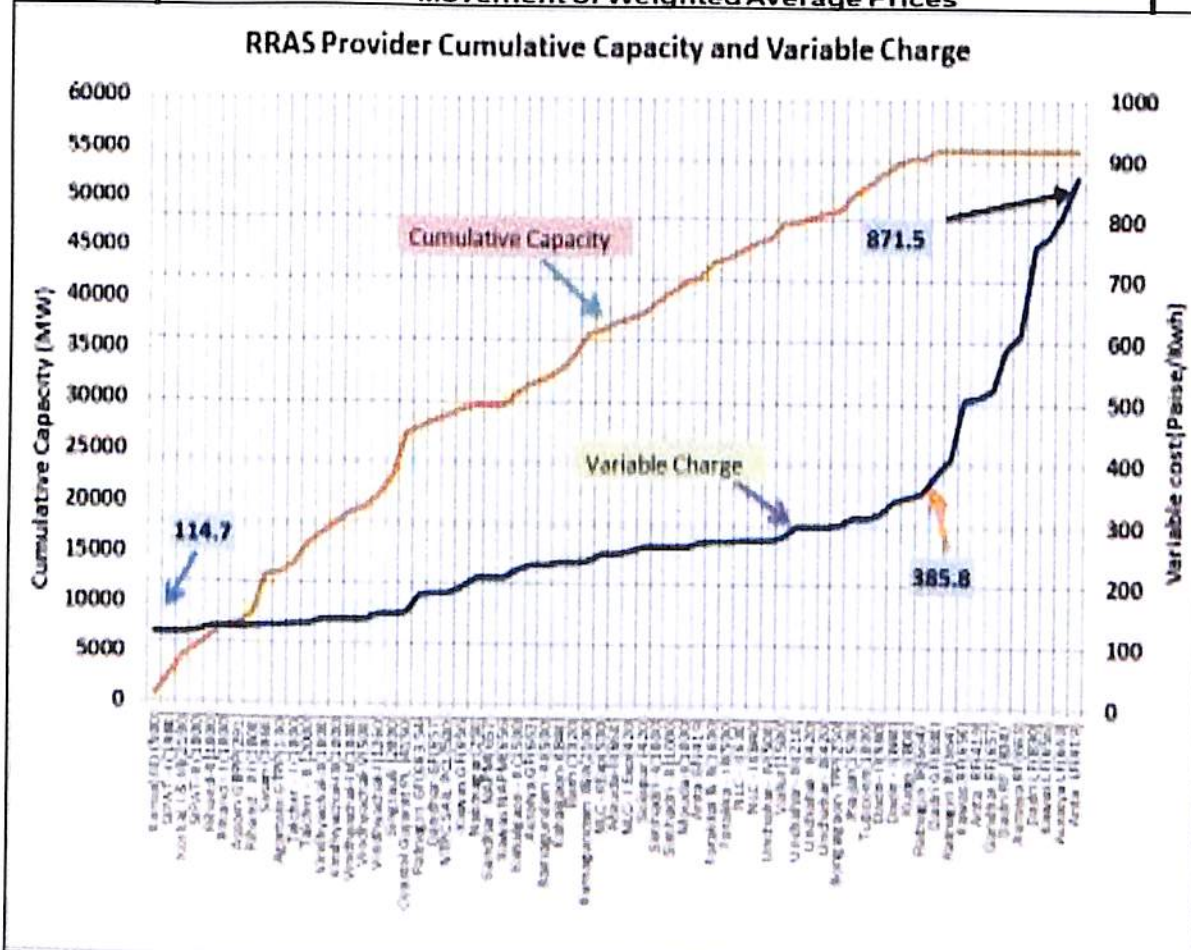
The DSM Regulations as notified in 2014 provide for revision of DSM price vector. A number of developments have taken place in the power sector since 2014. In this backdrop, the Commission considered it necessary to review the existing operational band of frequency with due regard to the need for safe, secure and reliable operation of the grid and review the principles of deviation settlement mechanism (DSM) rates, including their linkage with frequency in the light of the emerging market realities. Accordingly, the Commission vide its Office Order No. 1/2/2017/Exp.Group/CERC dated 27.04.2017, constituted an Expert Group (EG) under the Chairmanship of Shri A.S. Bakshi, Member, CERC and with representatives from CEA, POSOCO, CTU and CERC.

The Expert Group examined various features of inadvertent / unscheduled inter-change in India and other international markets. The EG examined the different market segments. Additionally, the cumulative capacity and variable charges of RRAS (Ancillary Services introduced since April, 2016) were also examined. Expert Group observed that the highest variable cost generator dispatched in Ancillary Services on daily basis during the period April 2016 to October 2017 has crossed the mark of more than Rs. 8 per unit on multiple occasions.

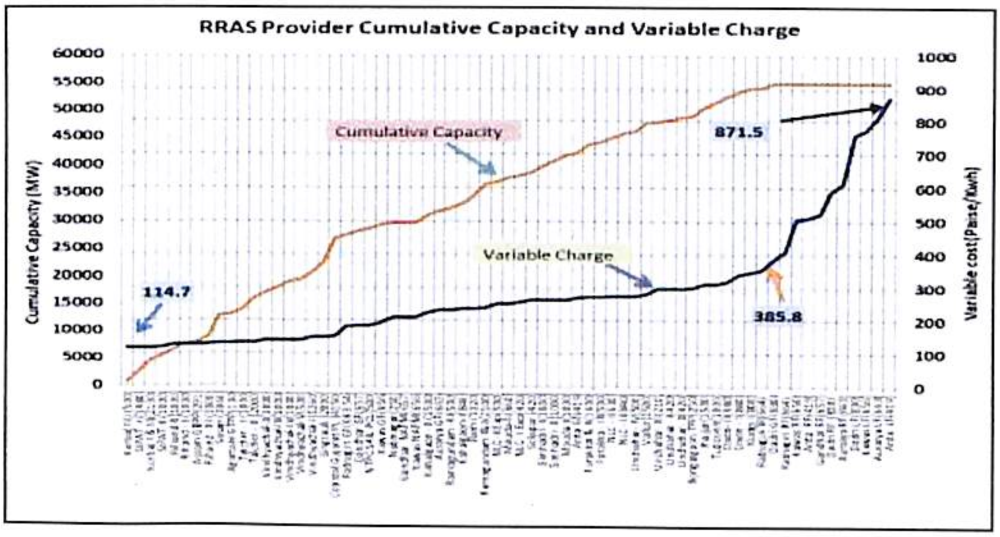
Weighted Average Prices in Different Market Segments

RRAS Provider Cumulative Capacity and Variable Charge

Movement of Weighted Average Prices



Highest Variable Cost Generation Despatched under Ancillary



Load forecasting:

According to Eugene A. Feinberg and Dora Genethliou State University of New York, Stony Brook

Load forecasts can be divided into three categories: short-term forecasts which are usually from one hour to one week, medium forecasts which are usually from a week to a year, and long-term forecasts which are longer than a year. Load forecasting has always been important for planning and operational decision conducted by utility companies. However, with the deregulation of the energy industries, load forecasting is even more important. With supply and demand fluctuating and the changes of weather condition and energy prices increasing by a factor of ten or more during peak situations, load forecasting is vitally important for utilities. Short-term load forecasting can help to estimate load flows and to make decisions that can prevent overloading. Load forecasting is also important for contract evaluations and evaluations of various sophisticated financial products on energy pricing offered by the market. In the deregulated economy, decisions on capital expenditures based on long-term forecasting are also more important than in a non-deregulated economy when rate increases could be justified by capital expenditure projects.

Medium and long-term load forecasting methods

The end-use modelling, econometric modelling and their combinations are the most often used methods for medium and long-term load forecasting. Descriptions of appliances used by customers, the sizes of the houses, the age of equipment, technology changes, customer behaviour and population dynamics are usually included in the statistical and simulation models based on the so-called end-use approach. In addition, economic factors such as per capita incomes, employment levels, and electricity prices are included in econometric models. These models are often used in combination with the end-use approach. Long-term forecasts include the forecasts on the population changes, economic development industrial construction, and technology development

a) **End-use models:** The end-use approach directly estimates energy consumption by using extensive information on end use and end users, such as appliances, the customer use, their age, sizes of houses, and so on. Statistical information about customers along with dynamics of change is the basis for the forecast.

b) **Econometric models:** The econometric approach combines economic theory and statistical techniques for forecasting electricity demand. The approach estimates the relationships between energy consumption (dependent variables) and factors influencing consumption. The relationships are estimated by the least-squares method or time series methods.

Short-term load forecasting methods

A large variety of statistical and artificial intelligence techniques have been developed for short-term load forecasting.

a) **Similar-day approach:** This approach is based on searching historical data for days within one, two, or three years with similar characteristics to the forecast day. Similar characteristics include weather, day of the week and the date. The load of a similar day is considered as a forecast. Instead of a single similar day load, the forecast can be a linear combination or regression procedure that can include several similar days. The trend coefficients can be used for similar days in the previous years.

b) **Regression methods:** Regression is the one of most widely used statistical techniques. For electric load forecasting regression methods are usually used to model the relationship of load consumption and other factors such as weather, day type, and customer class.

c) **Time series:** Time series methods are based on the assumption that the data have an internal structure, such as autocorrelation, trend or seasonal variation. Time series forecasting methods detect and explore such a structure. Time series have been used for decades in such fields as economics, digital signal processing, as well as electric load forecasting.

d) **Neural networks:** The use of artificial neural networks (ANN or simply NN) has been a widely studied electric load forecasting technique since 1990. Neural networks are essentially non-linear circuits that have the demonstrated capability to do non-linear curve fitting.

REVIEW AREA NARROW

CERC Regulation (5th amendment) currently in use and is of concern for the case study:

According to **No. L-1/132/2013-CERC** – In exercise of powers conferred by Section 178 of the Electricity Act, 2003 and all other powers enabling it in this behalf and after previous publication, the Central Electricity Regulatory Commission, hereby makes the following Regulations, to amend the Central Electricity Regulatory Commission (Deviation Settlement Mechanism and related matters) Regulations, 2014 namely:-

1. **Short Title and Comments**

a) These regulations may be called the Central Electricity Regulatory Commission (Deviation Settlement Mechanism and related matters) (Fifth Amendment) Regulations, 2019

b) These regulations shall come into force with effect from the date of notification in the official gazette

2. **Amendment to Regulation 2 of the Principal Regulations:**

2.1 A new sub-clause shall be added after sub-clause (ga) of clause (1) of Regulation 2 of the Principal Regulations, as under :- "(gb) **"Daily Base DSM"** means the sum of charges for deviations for all time blocks in a day payable or receivable as the case may be, excluding the additional charges under Regulation 7".

2.2 A new sub-clause shall be added after sub-clause (q) of clause (1) of Regulation 2 of the Principal Regulations, as under :- "(qa) **"Time Block DSM"** means the charge for deviation for the specific time block in a day payable or receivable as the case may be, excluding the additional charges under Regulation 7"

3. Amendment of Regulation 5 (Charges for Deviations) of the Principal Regulations:

3.1 The following new sub-clauses after sub-clause (d) in clause (2) of Regulation 5 of the Principal Regulations shall be inserted as under: -

"(e) The charges for inter-regional deviation and for deviation in respect of cross-Border transactions shall be computed on the basis of the unconstrained market clearing price in Day Ahead Market.

(f) The charges for deviation in respect of an entity falling in different bid areas, shall be computed on the basis of the daily average ACP of the bid area in which such entity has largest proportion of its demand."

3.2 such entity has largest proportion of its demand."

"The Cap rate for the charges for deviation for the generating stations, irrespective of the fuel type and whether the tariff of such generating station is regulated by the Commission or not, shall not exceed 303.04 Paisa/kWh."

4. Amendment of Regulation 7 (Limits on Deviation volume and consequences of crossing limits) of the Principal Regulation:

4.1 The following proviso under Regulation 7(1) of the Principal Regulations shall be deleted:

'Provided also that from a date not earlier than one year as may be notified by the Commission, the total deviation from schedule in energy terms during a day shall not be in excess of 3% of the total schedule for the drawer entities and 1% for the generators and additional charge of 20% of the daily base DSM payable / Receivable shall be applicable in case of said violation.

4.2 In Table-II of Regulation 7(3) of the Principal Regulations, the words "Cap Rate being equivalent to the energy charges as billed for the previous month" wherever they occur, shall be substituted by the words "Cap Rate for Deviation of 303.04 Paise/kWh".

4.3 The clause 4 of regulation 7 of the principal regulations shall be substituted as under:

"(4) In addition to Charges for Deviation as stipulated under Regulation 5 of these regulations, Additional Charge for Deviation shall be applicable for over-injection/under-drawal of electricity for each time block by a buyer/seller as the case may be when grid frequency is '50.10 Hz and above' at the rates equivalent to charges of deviation corresponding to the grid frequency of 'below 50.01 Hz but not below 50.0 Hz', or cap rate for deviation of 303.04 Paise/kWh whichever is lower."

4.4 In Proviso to clause (6) of Regulation 7 of the Principal Regulations, the words "Cap Rate equivalent to the energy charges as billed for the previous month" shall be substituted by the words "Cap Rate of 303.04 Paise/kWh".

4.5 In Proviso to clause (6) of Regulation 7 of the Principal Regulations, the words "Cap Rate equivalent to the energy charges as billed for the previous month" shall be substituted by the words "Cap Rate of 303.04 Paise/kWh".

a. Up to 31.03.2020, if the sustained deviation from schedule continues for 12 time blocks, the regional entity (buyer or seller), shall correct its position by making the sign of its deviation from schedule changed or by remaining in the range of +/- 20 MW with reference to its schedule, at least once, latest by13th time block.

Provided that each violation of the requirement under this clause shall attract an additional charge of 10% on the time block DSM payable / receivable as the case may be.

b. From 01.04.2020, if the sustained deviation from schedule continues for 6 time blocks, the regional entity (buyer or seller), shall correct its position, by making the sign of its deviation from schedule changed or by remaining in the range of +/- 20 MW with reference to its schedule, at least once, latest by 7th time block.

Provided that violation of the requirement under this clause shall attract an additional charge as specified in the table below:

No. of violations in a Day	**Additional Charge Payable**
From first to fifth violation	For each violation, an additional charge @ 3% of daily base DSM payable / receivable
From sixth to tenth violation	For each violation, an additional charge @ 5% of daily base DSM payable / receivable
From eleventh violation onwards	For each violation, an additional charge @ 10% of daily base DSM payable / receivable

4.6 The Clause 11 of the Regulation 7 of the Principal Regulations shall be substituted as follows:

"Payment of Charges for Deviation under Regulation 5 and the Additional Charges for Deviation under Clauses (3), (4) and (10) of this regulation, shall be levied without prejudice to any action that may be considered appropriate by the Commission under Section 142 of the Act for contravention of the provisions of the said regulations."

5. **Amendment of Annexure-I (Methodologies for the computation of Charges of Deviation for each regional entity for crossing the volume limits specified for the over-drawal / under-injection by Buyer / Seller [except Renewable Rich State]) of the Principal Regulations:-**

In Note under Illustration B in sub-clause (B)(iii) of clause 1 of Annexure-I to the Principal Regulations, the words "Cap Rate being equivalent to the energy charges as billed for the previous month" shall be substituted by the words "Cap Rate for Deviations of 303.04 Paise/kWh".

Available Transaction Short Term Scheduling options after CERC (DSM) Regulation

Balancing market and Scheduling options:

Transaction in UI by market participant's inter-alia may be attributed to poor demand forecasting and planning but there are real time concerns as well. These concerns are both on the demand and the generation sides. Recently, the Commission received petitions from state entities of Tripura and Madhya Pradesh citing difficulties in implementation of the deviation settlement mechanism regulations.

There are concerns of deviation from schedule that may not be in control of stateentities like

1) sudden load crash due to storm, heavy rainfall etc. or sudden increase in demand due
2) non-availability of corridor or congestion resulting in inability to schedule surplus power through open access/power exchange
3) unforeseen loss of generation

One way to deal with this is to provide markets that operate very close to the real time. In developed countries, balancing market is operated with the aim of settling imbalances in the electricity system from gate closure through to real time and is managed by system operators or balancing authorities (as system operators are called in some countries). In a good market design, generation should follow the load curve at all times even with a load that is constantly changing in real time. The demand and supply should be balanced in space and time, i.e.

generators' & beneficiaries' schedules match in each time block and across geography by taking into account transmission flows. In technical terms, the Area Control Error is to be minimized by monitoring the inter link power flows and frequency data. An important aspect of balancing is the approach to procuring ancillary services. The balancing of the demand and supply is achieved through primary response of generator which is immediate (frequency control) - Free Governor Mode of Operation (FGMO) and Restricted Governor Mode of Operation (RGMO); then through secondary response of generators (Automatic Generation Control) which may respond in a few minutes; and thereafter through tertiary response (operating reserves ancillary market) which responds in even longer time period. A special type of ancillary services is Demand Response that may even provide superior response to generators as curtailment of load is typically much faster than ramping of power plants.

Scheduled markets like intraday/contingency market operate close to gate closure and balance the demand and supply in a relatively longer period on a more sustained basis and by voluntary action of market. They also ensure security constrained merit order dispatch. When various forms of product are available in short term market as close to real time as possible and have enough liquidity, the generation is likely to follow the load curve in unison. With these products in the market, the generators tend to operate at optimal operational efficiency, the discom need not shed load to balance their portfolio and overall security constrained merit order is achieved through market mechanism similar to what can be achieved through centralized dispatch and the need for system operator to intervene through ancillary market is minimized.

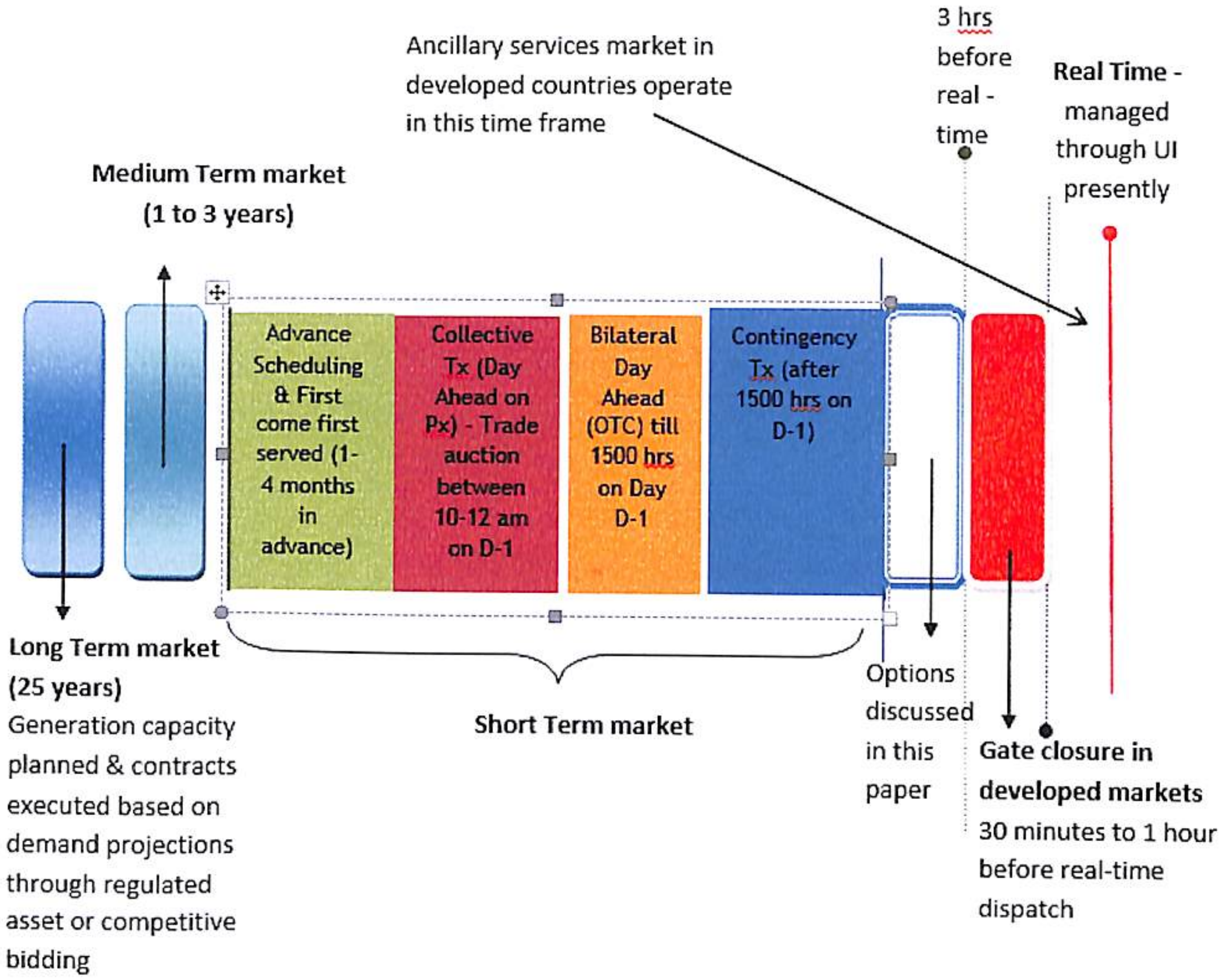
Intraday market enables buyers and sellers to transact energy within a day, and as close as possible to actual dispatch results in a more accurate generator resource despatch, maintaining system security, and reduction in area control errors during real time. With increasing shares of wind and solar generation, the uncertainty and variability in the net load (load minus wind and solar generation) is increasing. States have to either incur high UI charges or resort to load or RE curtailment. States with limited flexible generation sources can use intraday market to balance the errors between day-ahead schedule and real time dispatch.

As more variable RE generation get connected to the grid, the day-ahead forecast errors in net load are expected to increase and the need for intraday transactions and/or ancillary services that provide load following reserves will increase. An intraday market could provide a key platform that can be utilized to transact excess or deficit energy within a balancing area closer to real time dispatch.

Indian market design is decentralized dispatch concept where the merit ordering and scheduling responsibility is with the Discoms and the deviation settlement mechanism provides the Automatic Generation Control (AGC) for the Indian electricity grids and the whole design encourages the gencos/utilities to conserve when in the real time balance becomes surplus and to provide for when in there is a real time shortage and thus maintaining the grid frequency.

While UI is real time in nature and response to frequency variations is almost immediate by grid-connected entities, the options discussed in the paper (24x7 Intraday/contingency contracts & evening market) shall allow participants to trade 3-4 hours before the actual delivery as per the current mechanism. The present regulations allow scheduling of short-term bilateral transactions sixth time block onwards from the time of application but practically it requires at least 3-4 hours between trading auction and delivery of power. This gap is due to multiple concurrences required from NLDC, SLDCs & RLDCs. Hence, scheduled market discussed in the paper cannot be a one to one, or a 100% substitute of a real time mechanism and ancillary services should serve this segment better.

The figure below depicts the period in which trades are scheduled and ancillary market/UI are operated presently



2.3 FACTORS CRITICAL TO SUCCESS OF STUDY:

- Primary data collection techniques should be based on scientific methods.
- Reliability of secondary data.
- As the water inflows depends on many variables. Like snowfall during the previous year, weather conditions, rainfall, Temperature rise in the catchment area, these variables need to be monitor for proper forecasting of water inflows.
- Unpredictability of water inflows due flash floods during rainy seasons.
- Reliability of weather predictions, and weather station used for water forecasting.
- Fluctuation in sudden frequency due to load tripping or sudden power generation throw off not to be considered during the study.
- Storage capacity of reservoir to store surplus quantum of water.
- Quantitative methods used for the study.
- Ancillary services FGMO RGMO not to be considered during study.

- Snow accumulated data during the previous year in the catchment area.
- Ecological discharge and flushing water quantum is not considered during the study.
- Transmission losses also to be considered in the generation as the injection/metering point is 176 Km apart.

2.4 SUMMARY:

Primary scheduling is stochastic in nature whereas short term scheduling is deterministic. We are basically concerned with short term scheduling model. Short term scheduling can effect penalties/incentives current scenario of DSM during the summer season when there is plenty of water for generation. Management of water becomes critical during summer or rainy season operation of runoff hydro power plants. Many mathematical models have been functional in hydro power industry for optimal operation. But the effectiveness of such model varies from plant to plant as each power plant is functional in different internal and external environment. Therefore, a tailor made model is to be adopted for each plant. As far as CERC DSM regulation concerned they are also dynamic in nature, therefore, the operational strategy of plant needs to be reviewed or tested after enacting of latest DSM by CERC.

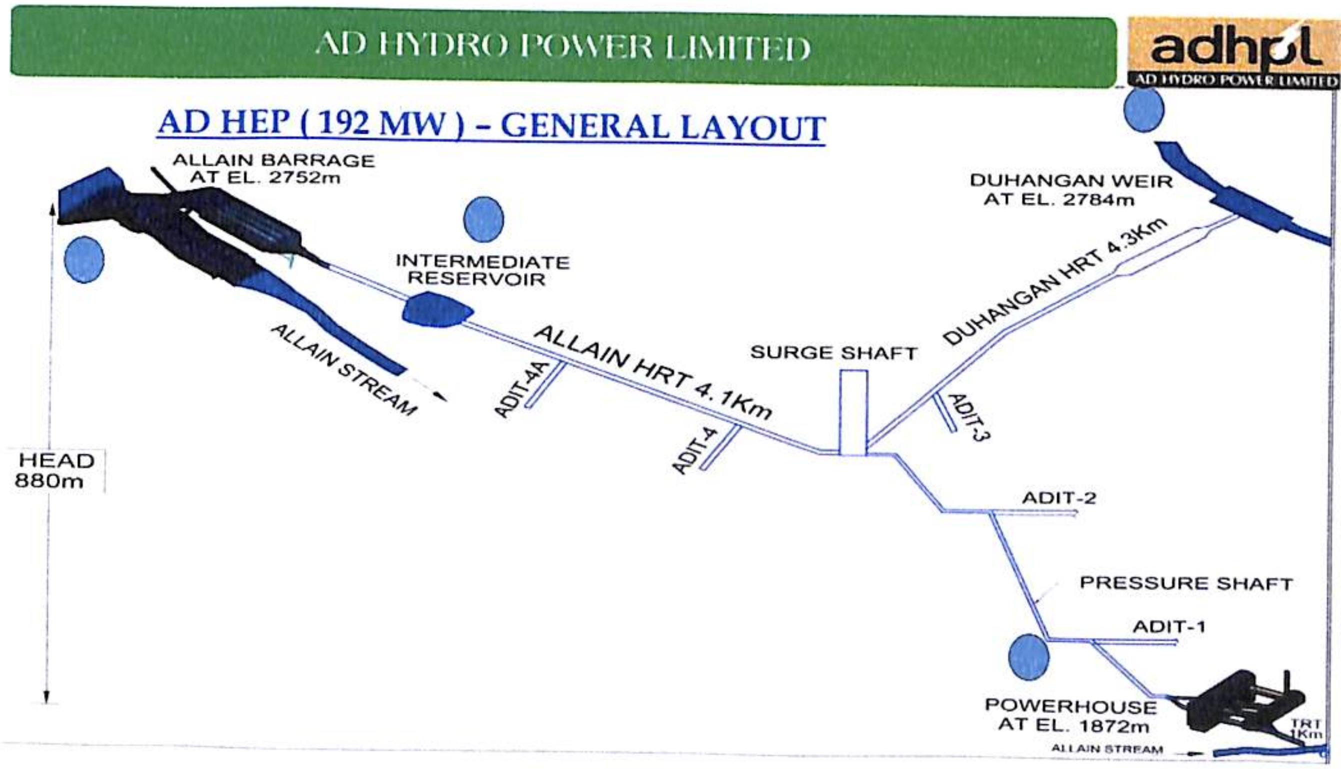
CHAPTER 3

Research Design, Methodology and Plan

The Case study approach research method will be used for the dissertation as we are dealing with a case study for AD Hydro Plant Only. The statistical and probability research tools to be used to collect data and analyze the primary and secondary data like straight line method, Moving average method, standard deviation and regression for forecasting purpose.

Our research design is based on short term scheduling of runoff river hydro power plants with small storage capacity to meet the fluctuation in short term demand for optimizing the generation considering the limitation of water forecasting and demand forecasting while hedging against CERC DSM.

ADHPL takes water from two stream Allain and Duhangan. Allain water can be regulated trough HR gates whereas the surplus water is spilled in main Allain downstream through spillway gate.



Duhangan Intake is a weir site from where fixed quantum of designed water intake is consider for generation during summer. The surplus water of both the streams can be accumulated in intermediate reservoir for meeting a small fluctuation in short term demand. The capacity of reservoir is to generate rated capacity of plant up to 2 hours only.

In our research study we will manage the water inflows and its storage according to optimum schedule in such a way that in short term scheduling is met for optimal generation and profit. ADHPL generates 7MW power from 1 cumecs of water inflow according to its design capacity.

Also the plant has to comply according to latest CERC DSM 5th regulation during the research as citied in paragraph below:

A regional entity having a sustained deviation from time blocks t_1 to t_{12}, should correct its position either by changing the sign of its deviation (from positive to negative or negative to positive as the case may be) or come back in the range of +/- 20 MW with reference to its schedule latest by the end of time block t_{13}. In case, such sign change does not take place or it fails to come back in the range of +/- 20 MW by the end of time block t_{13}, but such correction of position takes place from time block t_{14} up to time block t_{24}, then the additional charge shall be levied equivalent to one violation. The above violation shall attract an additional charge at the rate of 10% of the time block DSM for t_{13}. Further, in case, sign change does not take place or it fails to come back to the range as aforesaid even latest by the end of t_{25}, but correction of position takes place from time block t_{26} up to time block t_{36}, then the additional charge shall be levied equivalent to two violations. The above violation shall attract an additional charge at the rate of 10% of the time block DSM for t_{13} & t_{25},and so on.

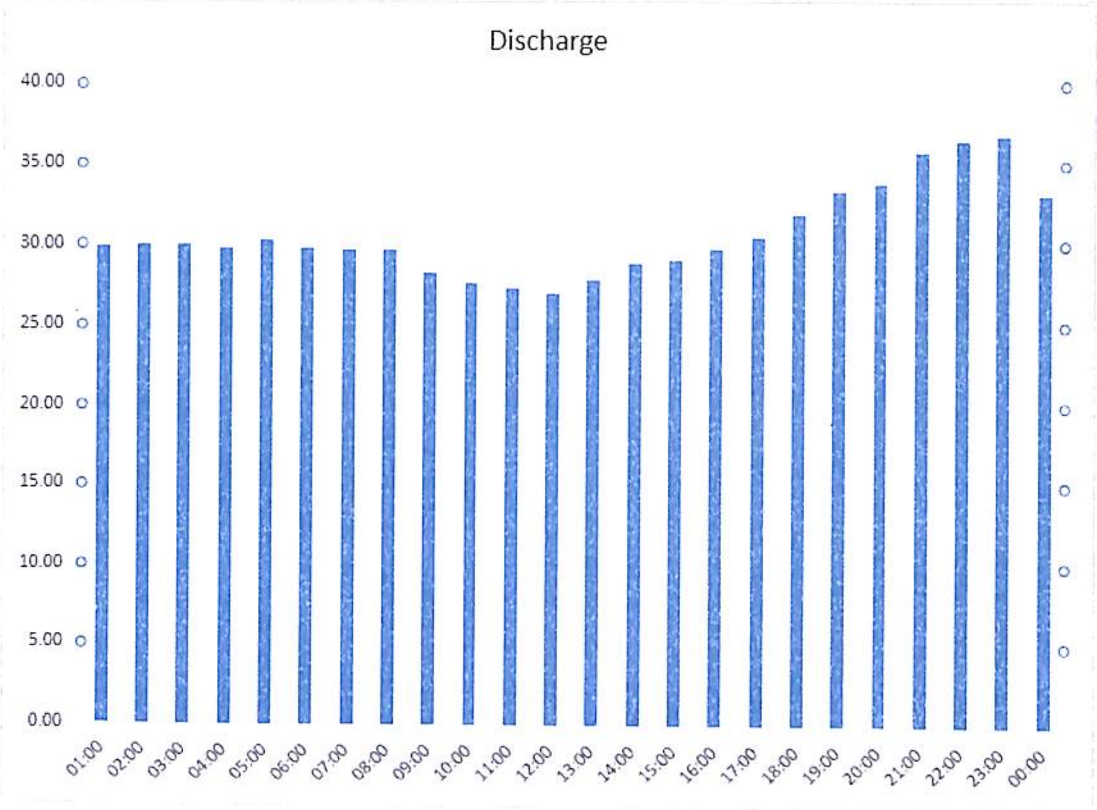
During our research ADHPL transmission losses are also to be considered in the generation schedule as the injection/metering point is 176 Km away.

3.1 Data Sources

Primary data: is collected from weather station installed at our remote site, previous year water inflows data collected by AD hydro. Load or demand data for previous years in the form of frequency stored in log sheets. Rainfall data for previous years. Snow accumulated from the previous year's data collected by AD Hydro.

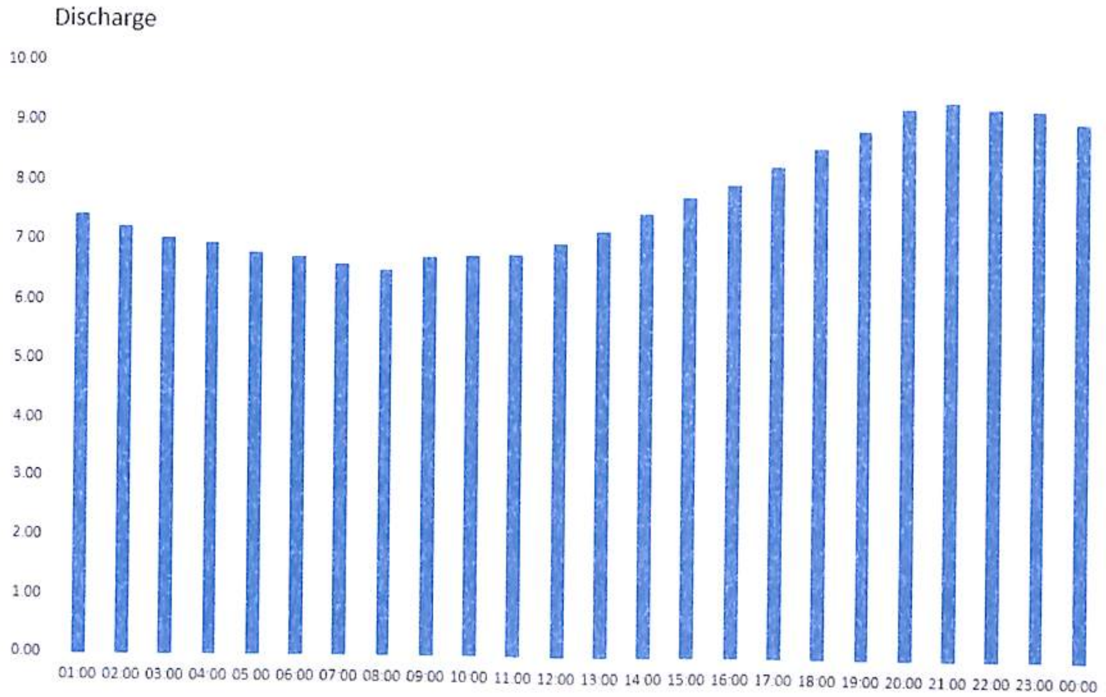
Secondary Data: the source for secondary data is mainly Government agencies like Meteorological sites. IMD and NRLDC.

time	Discharge
01:00	29.88
02:00	29.93
03:00	29.96
04:00	29.73
05:00	30.31
06:00	29.80
07:00	29.70
08:00	29.65
09:00	28.25
10:00	27.60
11:00	27.30
12:00	27.00
13:00	27.80
14:00	28.80
15:00	29.00
16:00	29.80
17:00	30.50
18:00	31.90
19:00	33.33
20:00	33.83
21:00	35.83
22:00	36.53
23:00	36.83
00:00	33.07



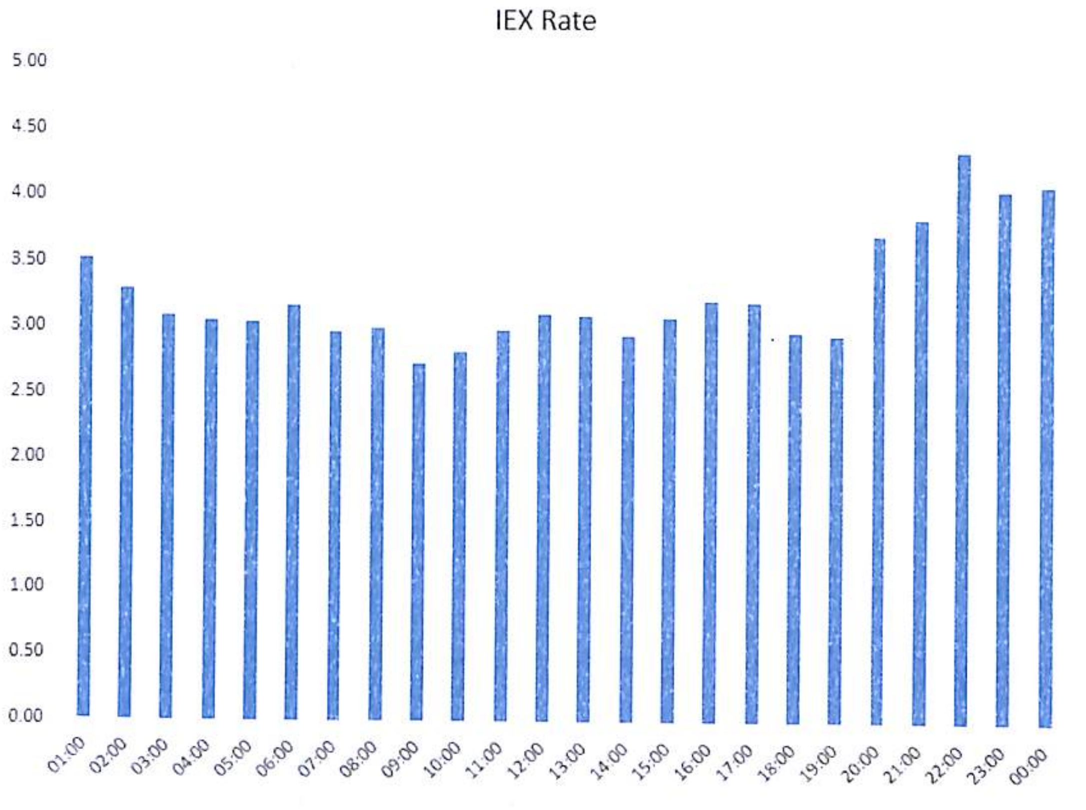
14 August 2019 Discharge Trend

Time	Discharge
01:00	7.43
02:00	7.23
03:00	7.03
04:00	6.95
05:00	6.82
06:00	6.75
07:00	6.62
08:00	6.54
09:00	6.74
10:00	6.77
11:00	6.80
12:00	6.99
13:00	7.20
14:00	7.49
15:00	7.79
16:00	7.99
17:00	8.29
18:00	8.59
19:00	8.90
20:00	9.29
21:00	9.40
22:00	9.29
23:00	9.26
00:00	9.06



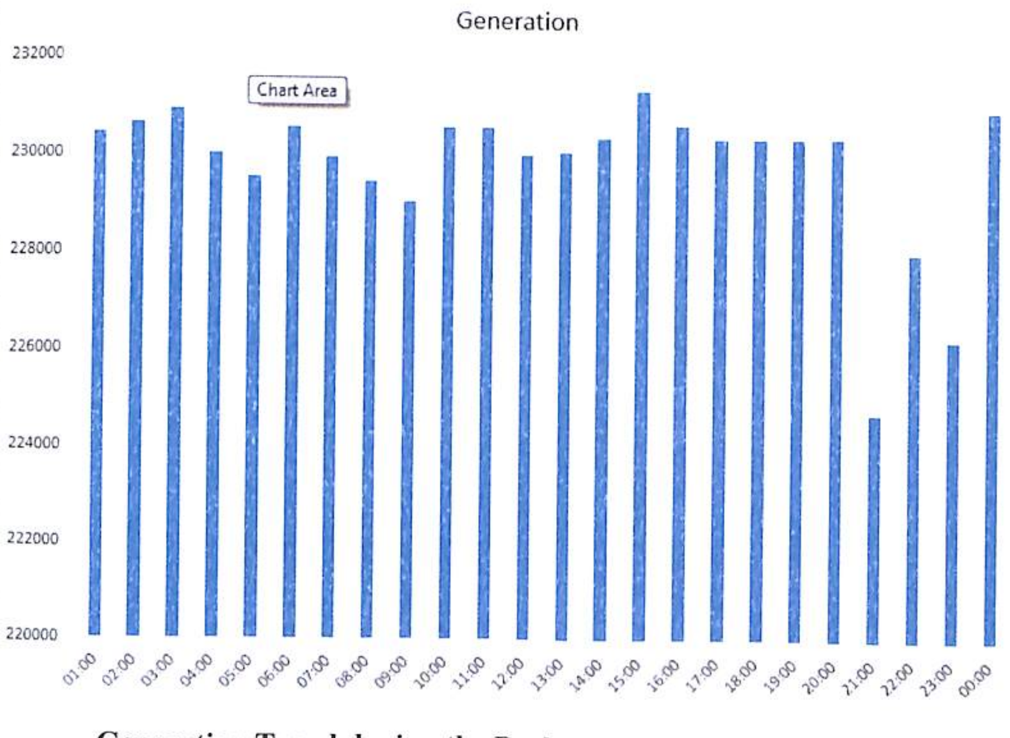
18 April 2019 Discharge Trend

Time	IEX Rate
01:00	3.52
02:00	3.29
03:00	3.09
04:00	3.05
05:00	3.04
06:00	3.17
07:00	2.96
08:00	2.99
09:00	2.73
10:00	2.82
11:00	2.99
12:00	3.11
13:00	3.09
14:00	2.94
15:00	3.08
16:00	3.20
17:00	3.20
18:00	2.97
19:00	2.95
20:00	3.70
21:00	3.82
22:00	4.34
23:00	4.04
00:00	4.07



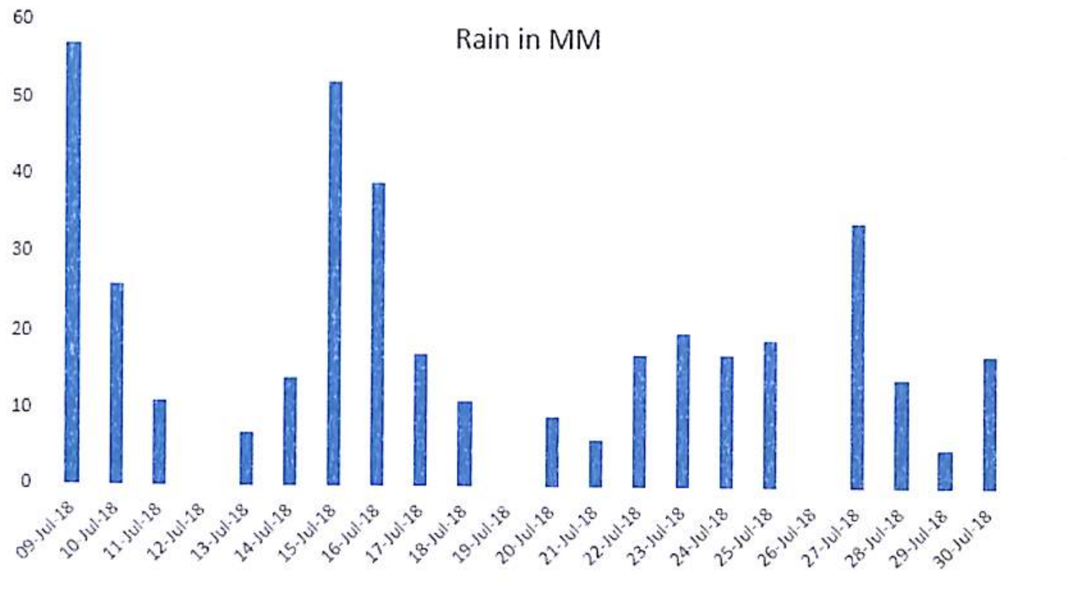
IEX Rate Trend during the day

Time	Generation
01:00	230440
02:00	230650
03:00	230930
04:00	230020
05:00	229530
06:00	230580
07:00	229950
08:00	229460
09:00	229040
10:00	230580
11:00	230580
12:00	230020
13:00	230090
14:00	230370
15:00	231350
16:00	230650
17:00	230370
18:00	230370
19:00	230370
20:00	230370
21:00	224700
22:00	227990
23:00	226240
00:00	230930

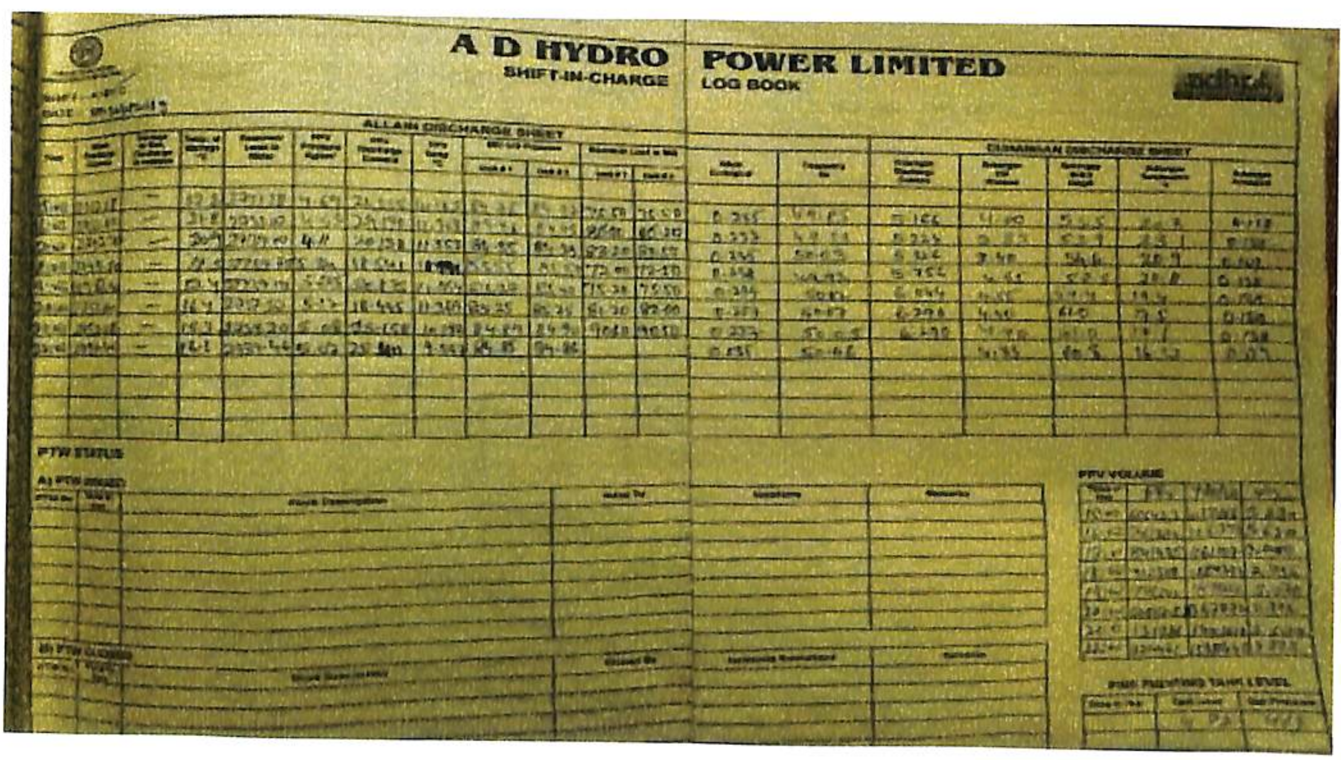


Generation Trend during the Peak season

Date	Rain in MM
09-Jul-18	57
10-Jul-18	26
11-Jul-18	11
12-Jul-18	0
13-Jul-18	7
14-Jul-18	14
15-Jul-18	52
16-Jul-18	39
17-Jul-18	17
18-Jul-18	11
19-Jul-18	0
20-Jul-18	9
21-Jul-18	6
22-Jul-18	17
23-Jul-18	20
24-Jul-18	17
25-Jul-18	19
26-Jul-18	0
27-Jul-18	34
28-Jul-18	14
29-Jul-18	5
30-Jul-18	17



Secondary Data from Heli ski (Forecasting of Rain fall)



Primary Data Collected from Various ADHPL Sites

3.2 Research Design

Decrease in percentage deviation:

1) Input of day ahead weather forecast from various websites.
2) Analysis of actual data of previous day discharge trend and current discharge trend.
3) Analysis of actual data of previous 3 days & current temperature. Trend from Allain & Duhangan sites and also PPV inlet water temperature trend.
4) Based on calculation and prediction of input and actual data, along with previous experience hourly discharge forecasted.
5) Monitoring of weather forecasting sites on regular basis say every 4 Hours and its effect on current discharge.
6) Evaluation of actual vs. forecasted discharge monthly basis.
7) Based on above evaluation corrective measures/suggestions to improve discharge forecasting and to reduce the deviation.

Maximum running hours above cut-off load

1) Defining of load with machine efficiency above 83%. Based on the efficiency sheet.
2) Scheduling considering the defined /cut off load as far as possible.
3) Recording data of running hours & hourly average load.
4) Daily monitoring and analysis of machine efficiency.
5) Redefining of load (Considered in Activity #1) if any change in efficiency observed.
6) Evaluation of running Hours vs. Load so as to ensure/ confirm the objective.

Reduction in UI chargeable

1) Regular analysis of UI- Deviation Settlement Account statement (DSA) for better scheduling & better UI realisation.
2) Accounting of transmission losses w.r.t. DSA so as to confirm/modify them in scheduling.
3) Monthly analysis for evaluation of objectives and accordingly implementation of corrective measures/ Suggestion.
4) Final evaluation of objective.

Short-term load forecasting methods used in research design:

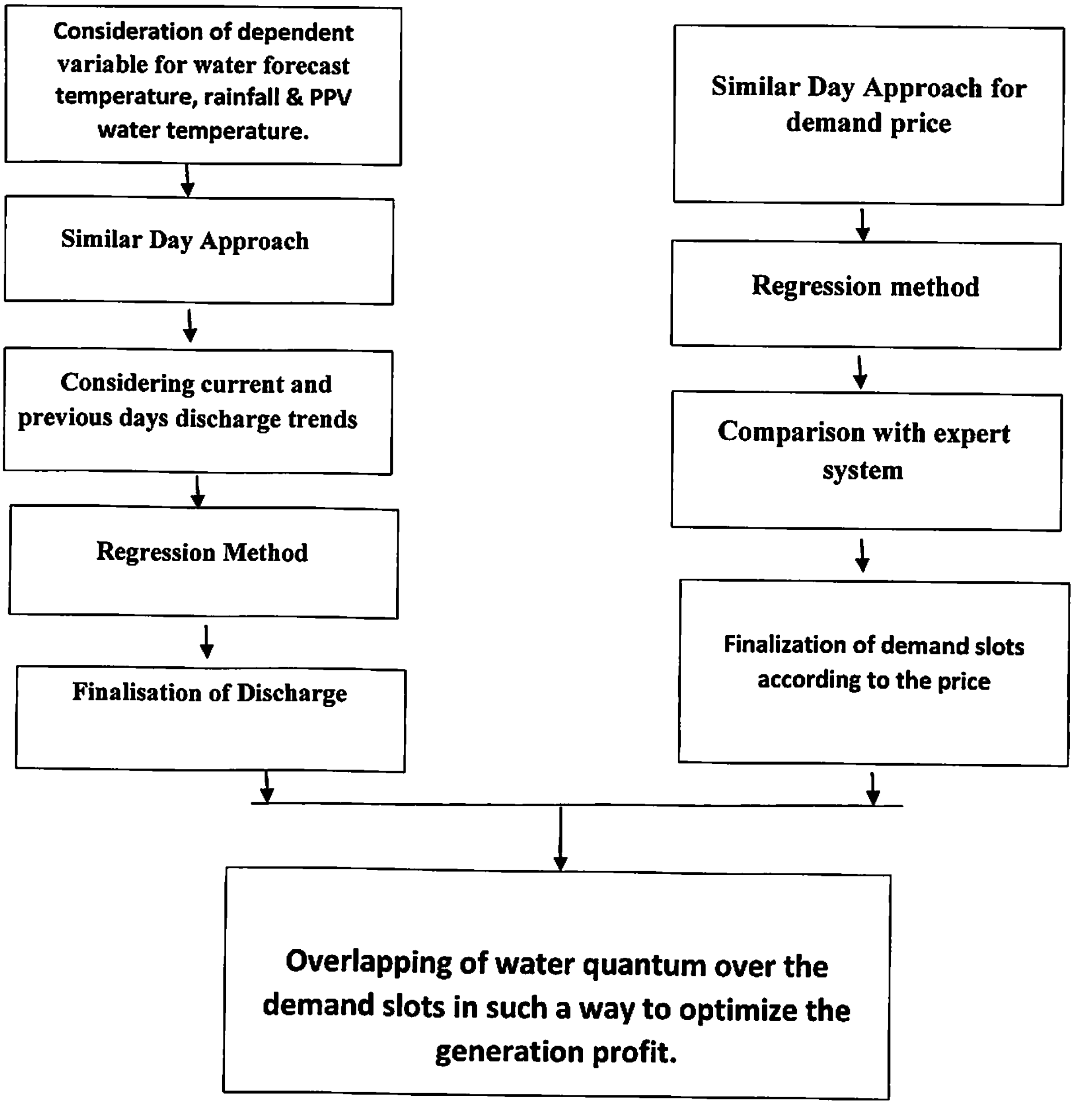
A large variety of statistical and artificial intelligence techniques have been developed for short-term load forecasting.

Similar-day approach. This approach is based on searching historical data for days within one, two or three years with similar characteristics to the forecast day. Similar characteristics include weather, day of the week, and the date. The load of a similar day is considered as a forecast. Instead of a single similar day load, the forecast can be a linear combination or regression procedure that can include several similar days. The trend coefficients can be used for similar days in the previous years.

Regression methods. Regression is the one of most widely used statistical techniques. For electric load forecasting regression methods are usually used to model the relationship of load consumption and other factors such as weather, day type and customer class.

Expert systems. Rule based forecasting makes use of rules, which are often heuristic in nature, to do accurate forecasting. Expert systems, incorporate rules and procedures used by human experts in the field of interest into software that is then able to automatically make forecasts without human assistance.

Research Design for Optimizing Generation Profit



3.3 Survey Questions:

1. What strategy AD hydro is using for Operation of plant?
2. How the primary data is gathered for generation?
3. How accurate is the generation prediction using primary data?
4. What is the procedure for analysing the Data?
5. What tools AD hydro uses for scheduling and water forecasting?
6. How AD hydro is managing water inflows after DSM implementation?

3.4 Interview Procedures:

Primary data is gathered in the control room from different project sites through telephone. Like discharge of both streams (Allain & Duhangan), PPV temperature, temperature of various sites and reservoir level etc.

Operational strategy discussed with the operation staff about the water management, demand forecasting and DSM regulation. Shift in charges interviewed personally for the questions mentioned in survey questions.

3.5 Data Analysis Procedures:

1) Input of day ahead weather forecast from various websites.
2) Analysis of actual data of previous day discharge trend and current discharge trend.
3) Analysis of actual data of previous 3 days & current temperature trend from Allain & Duhangan sites and also PPV inlet water temperature trend.
4) Based on calculation and prediction of input and actual data along with previous experience, hourly discharge is forecasted.
5) Monitoring of weather forecasting sites on regular basis say every 4 Hours and its effect on current discharge.
6) Evaluation of actual vs. forecasted discharge on monthly basis.
7) Based on above evaluation corrective measures/suggestions to improve discharge forecasting and to reduce the deviation.
8) Analysis data is sent to expert system i.e. to power trading agency Statkraft for validation and suggestion.

Chapter 4

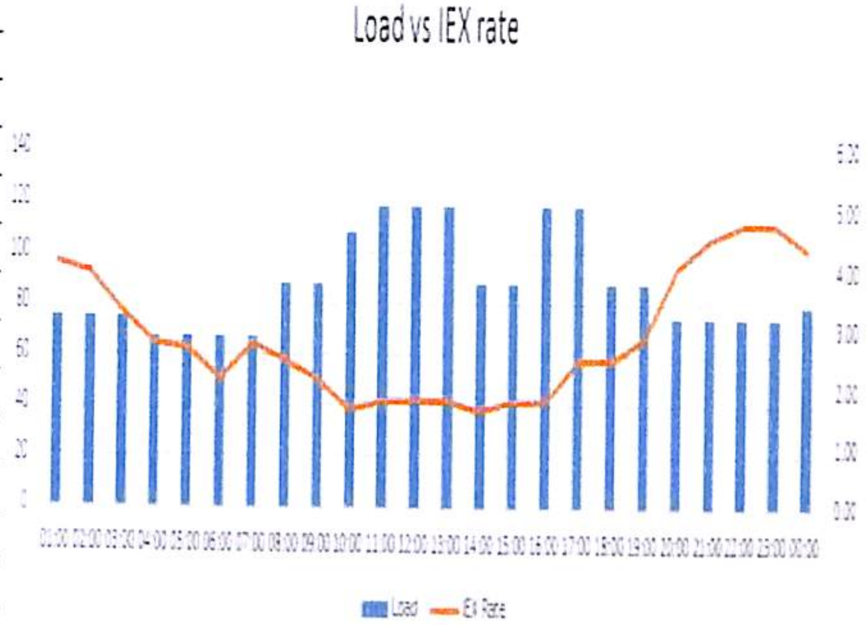
Finding and Analysis

4.1 Descriptive Statistics.

Load forecasting

The below figure shows the bad schedule forecasting where the quantum of power generated taking the limitation of water inflow is not superimposed according to forecasted rates.

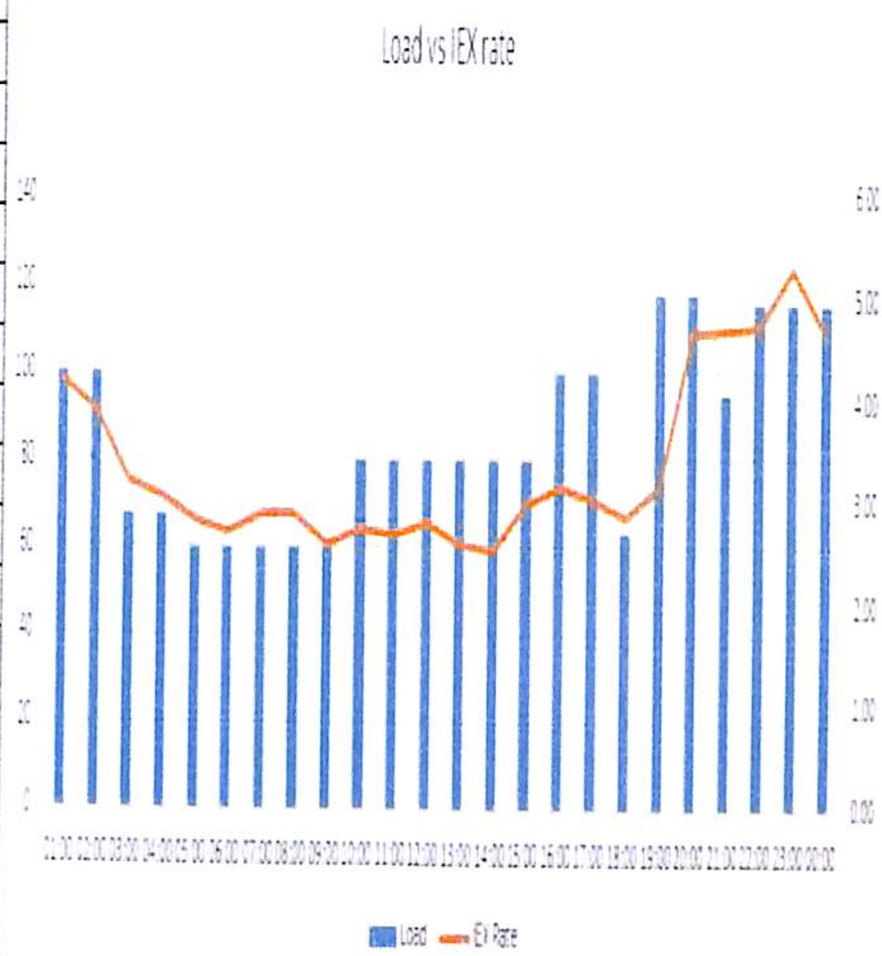
Date	Time	Load	IEX Rate
09-Sep-19	01:00	75	4.11
	02:00	75	3.97
	03:00	75	3.30
	04:00	67	2.77
	05:00	67	2.69
	06:00	67	2.19
	07:00	67	2.77
	08:00	88	2.49
	09:00	88	2.15
	10:00	108	1.66
	11:00	118	1.80
	12:00	118	1.80
	13:00	118	1.80
	14:00	88	1.64
	15:00	88	1.80
	16:00	118	1.80
	17:00	118	2.50
	18:00	88	2.50
	19:00	88	2.84
	20:00	75	4.06
	21:00	75	4.52
	22:00	75	4.79
	23:00	75	4.75
	00:00	80	4.35



Bad Scheduling

The below figure shows the good schedule forecasting where the quantum of power generated taking the limitation of water inflow is properly superimposed according to forecasted rates.

	01:00	100	4.20
	02:00	100	3.92
	03:00	67	3.24
	04:00	67	3.09
	05:00	60	2.84
	06:00	60	2.73
	07:00	60	2.91
	08:00	60	2.89
	09:00	60	2.60
	10:00	80	2.75
	11:00	80	2.68
11-Sep-19	12:00	80	2.80
	13:00	80	2.61
	14:00	80	2.55
	15:00	80	2.98
	16:00	100	3.15
	17:00	100	3.06
	18:00	63	2.86
	19:00	118	3.18
	20:00	118	4.68
	21:00	95	4.72
	22:00	116	4.75
	23:00	116	5.30
	00:00	116	4.67



Good Scheduling

From the above case we can see that during bad scheduling average generation is 87.45 MWh and the average price for the day is Rs. 2.88, but in case of good scheduling the average generation is less i.e. 85.66 MWh but the average price is high i.e. Rs. 3.38 when we adopt proper methodology forecasting the IEX rates by using statistical analysis of IEX rates during the previous days.

The descriptive statistical methods used for good scheduling considering proper water management of water to hedge DSM and proper IEX rates forecasting.

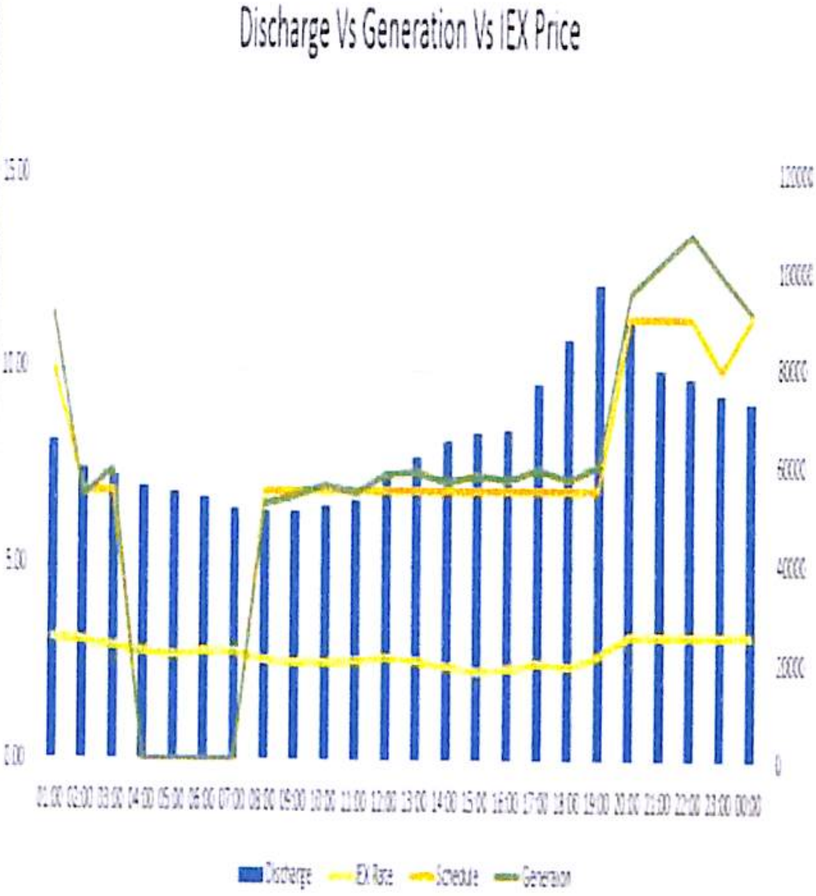
The below example shows the DSM penalties imposed by CERC regulations during the month of April. Despite of less inflows water is not managed properly and DSM penalties imposed on the entity.

Entity : ADHPL

DATE	SCHDL(LU)	ACTUAL(LU)	DEVI AMT	SUS DEVI	SUS AMOUNT	ADD DEVI	ADJ ON A C OF NU CSTN & IW	NET DEVI
15.04.2019	11.46030	12.53819	-2.40399	4	1.92319	0.36555	0.00000	-0.11495
16.04.2019	12.41530	14.42575	-2.92675	8	4.65250	2.30809	0.00000	4.06414
17.04.2019	15.27430	13.54204	2.85455	2	1.14182	0.04728	0.00000	4.04365
18.04.2019	12.88640	10.55904	5.62740	3	3.37644	0.10542	0.00000	9.10926
19.04.2019	10.98630	10.19990	1.91568	0	0.00000	0.02944	0.00000	1.94512
20.04.2019	10.51230	11.66952	-3.33981	2	1.33592	0.06923	0.00000	-1.93466
21.04.2019	12.40660	14.13487	-1.62974	8	7.40758	0.18477	0.00000	2.96261
Total	85.94130	87.06931	-2.90266	27	19.86775	3.11008	0.00000	20.07517

21 April 2019

Time	Discharge	Schedule	Generation	Deviation	IEX Rate
01:00	8.20	80901	91840	10939	3.18
02:00	7.50	55550	54040	-1510	3.07
03:00	7.30	55550	59710	4160	2.92
04:00	7.00	0	0	0	2.78
05:00	6.90	0	0	0	2.75
06:00	6.77	0	0	0	2.82
07:00	6.50	0	0	0	2.81
08:00	6.40	55550	52500	-3050	2.56
09:00	6.39	55550	54530	-1020	2.55
10:00	6.51	55550	56420	870	2.54
11:00	6.71	55550	54880	-670	2.60
12:00	7.30	55550	58730	3180	2.67
13:00	7.80	55550	59290	3740	2.59
14:00	8.20	55550	57190	1640	2.42
15:00	8.40	55550	58520	2970	2.29
16:00	8.50	55550	57680	2130	2.38
17:00	9.70	55550	59920	4370	2.52
18:00	10.80	55550	57540	1990	2.44
19:00	12.19	55550	60130	4580	2.72
20:00	11.20	90565	95480	4915	3.24
21:00	10.00	90565	101570	11005	3.24
22:00	9.80	90565	108080	17515	3.24
23:00	9.40	79696	99330	19634	3.24
00:00	9.20	90565	91700	1135	3.26



Above shown graph clearly indicates the following stats: -

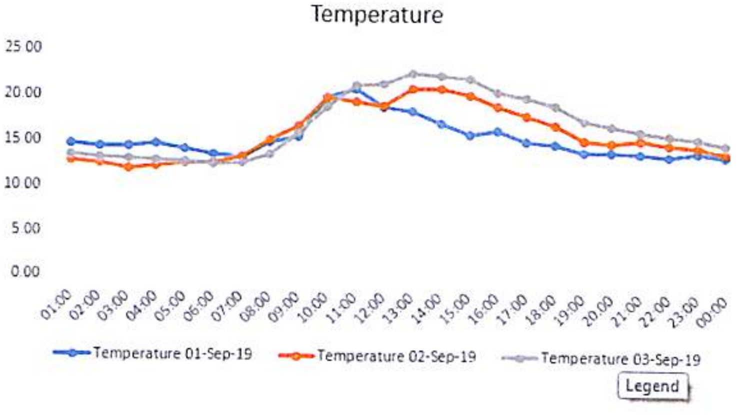
Sr. No.	Statistics	Discharge (In Cumecs)	Schedule (In KW)	Generation (In KW)	Deviation (IN KW)	IEX Rate (In Rupees)
1	Average	8.61	54190	57878	3689	2.78
2	Min	6.39	90565	0	-3050	2.29
3	Max	12.19	0	108080	19634	3.26
4	Sum/Total	155.01	1300555	1389080	88525	66.84

It is clear from the Schedule for 21st April 2019 that the forecasting of discharge and IEX rates not considered and thereby having DSM penalties and hampered the profit due to improper scientific scheduling.

4.2 Correlation and Regression

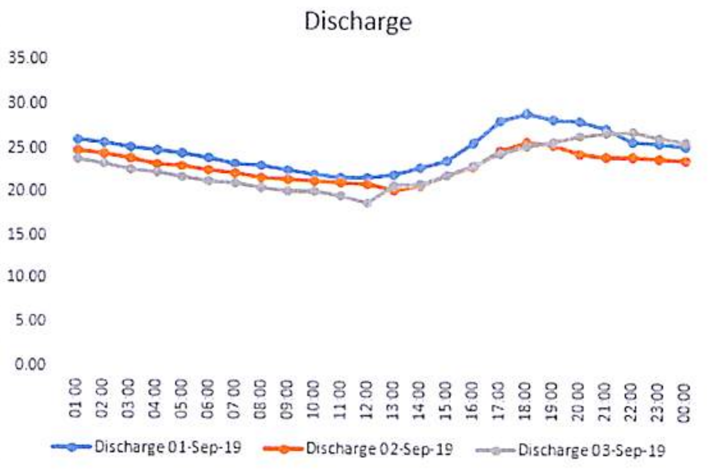
Scheduling results after following research Design

Time	Temperature		
	01-Sep-19	02-Sep-19	03-Sep-19
01:00	14.70	12.90	13.50
02:00	14.50	12.60	13.20
03:00	14.50	12.10	13.10
04:00	14.70	12.30	12.90
05:00	14.20	12.70	12.80
06:00	13.60	12.70	12.50
07:00	13.20	13.40	12.70
08:00	15.00	15.20	13.50
09:00	15.60	16.70	16.00
10:00	20.00	19.90	18.90
11:00	20.90	19.50	21.30
12:00	18.90	19.10	21.50
13:00	18.50	21.10	22.70
14:00	17.10	21.10	22.40
15:00	15.80	20.30	22.10
16:00	16.30	19.10	20.60
17:00	15.10	18.00	20.00
18:00	14.70	16.90	19.00
19:00	13.90	15.30	17.30
20:00	13.80	15.00	16.70
21:00	13.70	15.20	16.10
22:00	13.40	14.70	15.70
23:00	13.90	14.40	15.40
00:00	13.40	13.90	14.80



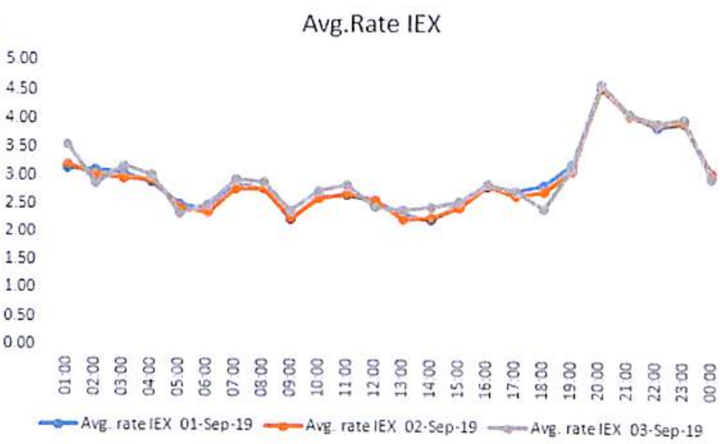
Same day approach for Temperature trends

Time	Discharge		
	01-Sep-19	02-Sep-19	03-Sep-19
01:00	26.05	24.91	23.78
02:00	25.71	24.53	23.28
03:00	25.13	23.97	22.59
04:00	24.78	23.40	22.38
05:00	24.59	23.11	21.83
06:00	23.95	22.70	21.34
07:00	23.31	22.36	21.09
08:00	23.17	21.85	20.66
09:00	22.58	21.73	20.34
10:00	22.13	21.45	20.25
11:00	21.82	21.35	19.83
12:00	21.79	21.21	18.90
13:00	22.17	20.52	20.93
14:00	22.92	21.03	21.20
15:00	23.92	22.24	22.08
16:00	25.93	23.19	23.30
17:00	28.42	25.01	24.73
18:00	29.30	26.12	25.58
19:00	28.54	25.63	26.00
20:00	28.45	24.61	26.65
21:00	27.57	24.40	27.06
22:00	26.02	24.30	27.21
23:00	25.88	24.21	26.52
00:00	25.53	24.04	26.05



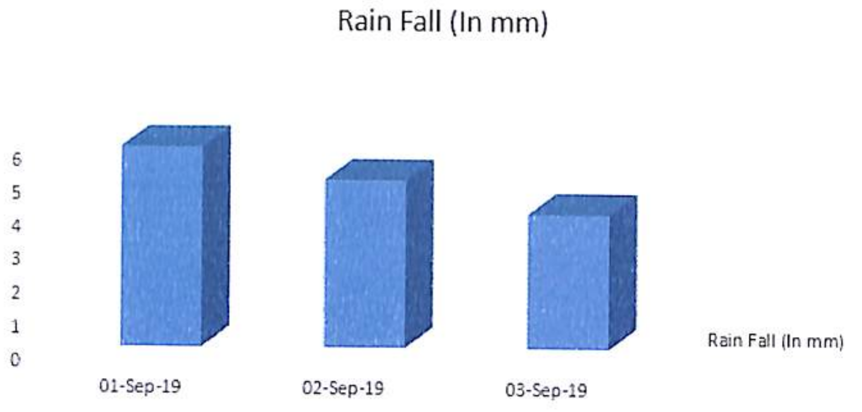
Same Day approach for discharge trend

Time	Avg. rate IEX		
	01-Sep-19	02-Sep-19	03-Sep-19
01:00	3.13	3.23	3.57
02:00	3.12	3.05	2.89
03:00	3.06	2.99	3.20
04:00	2.90	2.97	3.05
05:00	2.51	2.47	2.35
06:00	2.41	2.39	2.52
07:00	2.84	2.80	2.97
08:00	2.81	2.79	2.90
09:00	2.25	2.29	2.40
10:00	2.67	2.65	2.78
11:00	2.69	2.73	2.89
12:00	2.60	2.63	2.50
13:00	2.35	2.29	2.43
14:00	2.25	2.31	2.50
15:00	2.55	2.49	2.60
16:00	2.84	2.87	2.90
17:00	2.78	2.71	2.78
18:00	2.88	2.78	2.45
19:00	3.25	3.15	3.20
20:00	4.57	4.61	4.65
21:00	4.14	4.10	4.13
22:00	3.91	3.95	3.97
23:00	3.97	4.00	4.05
00:00	3.12	3.10	3.01



Same Day approach for IEX trend

Date	Rain Fall (In mm)
01-Sep-19	6
02-Sep-19	5
03-Sep-19	4



Trends for Rainfall

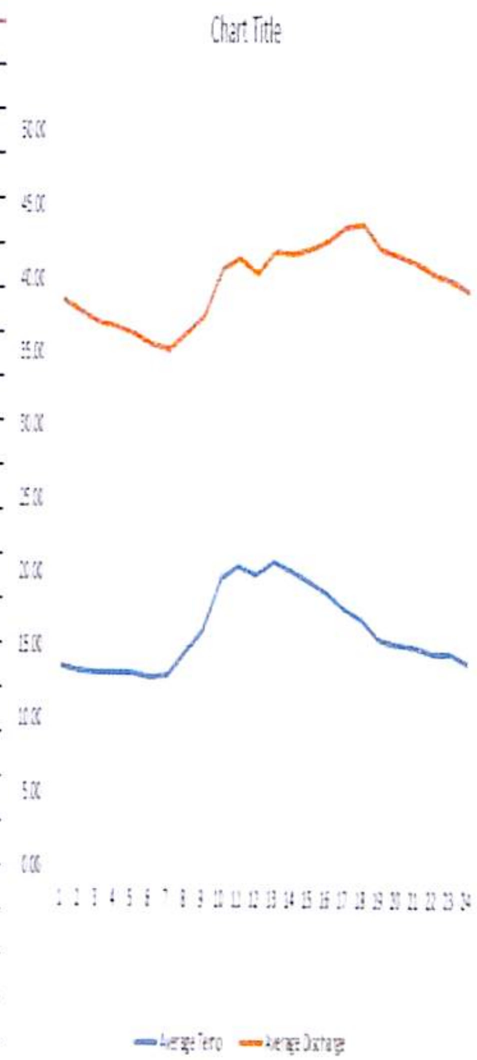
Discharge dependent variable depends on temperature and rainfall.

Water forecasting using regression.

Water discharge depends on the temperature. As the temperature increases the snow melts and water increases and vice versa. The rainfall is almost constant for the previous 3 days so it is not considered in this case.

As per our research model the water forecasting is done by taking the average of both the quantity from the previous day's data after that the regression analysis is used to forecast discharge of water depending on the temperature variable.

Time	Discharge			Time	Temperature			Average Temp	Average Discharge
	01-Sep-19	02-Sep-19	03-Sep-19		01-Sep-19	02-Sep-19	03-Sep-19		
01:00	25.05	24.91	23.78	01:00	14.70	12.90	13.50	13.70	24.92
02:00	25.71	24.53	23.28	02:00	14.50	12.60	13.20	13.43	24.51
03:00	25.13	23.97	22.59	03:00	14.50	12.10	13.10	13.23	23.90
04:00	24.78	23.40	22.38	04:00	14.70	12.30	12.90	13.30	23.52
05:00	24.59	23.11	21.63	05:00	14.20	12.70	12.80	13.23	23.17
06:00	23.95	22.70	21.34	06:00	13.60	12.70	12.50	12.93	22.67
07:00	23.31	22.36	21.09	07:00	13.20	13.40	12.70	13.10	22.25
08:00	23.17	21.85	20.66	08:00	15.00	15.20	13.50	14.57	21.90
09:00	22.58	21.73	20.34	09:00	15.60	16.70	16.00	16.10	21.55
10:00	22.13	21.45	20.25	10:00	20.00	19.90	18.90	19.60	21.27
11:00	21.82	21.35	19.83	11:00	20.90	19.50	21.30	20.57	21.00
12:00	21.79	21.21	18.90	12:00	18.90	19.10	21.50	19.83	20.63
13:00	22.17	20.52	20.93	13:00	18.50	21.10	22.70	20.77	21.21
14:00	22.92	21.03	21.20	14:00	17.10	21.10	22.40	20.20	21.72
15:00	23.52	22.24	22.08	15:00	15.80	20.30	22.10	19.40	22.75
16:00	25.93	23.19	23.30	16:00	16.30	19.10	20.60	18.67	24.14
17:00	28.42	25.01	24.73	17:00	15.10	18.00	20.00	17.70	26.06
18:00	28.30	26.12	25.58	18:00	14.70	16.90	19.00	16.87	27.00
19:00	28.54	25.63	26.00	19:00	13.90	15.30	17.30	15.50	26.72
20:00	28.45	24.61	26.65	20:00	13.80	15.00	16.70	15.17	26.57
21:00	27.57	24.40	27.06	21:00	13.70	15.20	16.10	15.00	26.34
22:00	26.02	24.30	27.21	22:00	13.40	14.70	15.70	14.60	25.84
23:00	25.88	24.21	26.52	23:00	13.90	14.40	15.40	14.57	25.54
00:00	25.53	24.04	26.05	00:00	13.40	13.90	14.80	14.03	25.21



Average Temperature and discharge for the previous day

The water forecasting equation depending on the temperature

Y (discharge) = A+B*X (temp), Y=29.02355+(-0.3268)*X(temp)

For the above discharge and temperature data the regression stats is shown below.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.436330346
R Square	0.190384171
Adjusted R Square	0.153583452
Standard Error	1.901845477
Observations	24

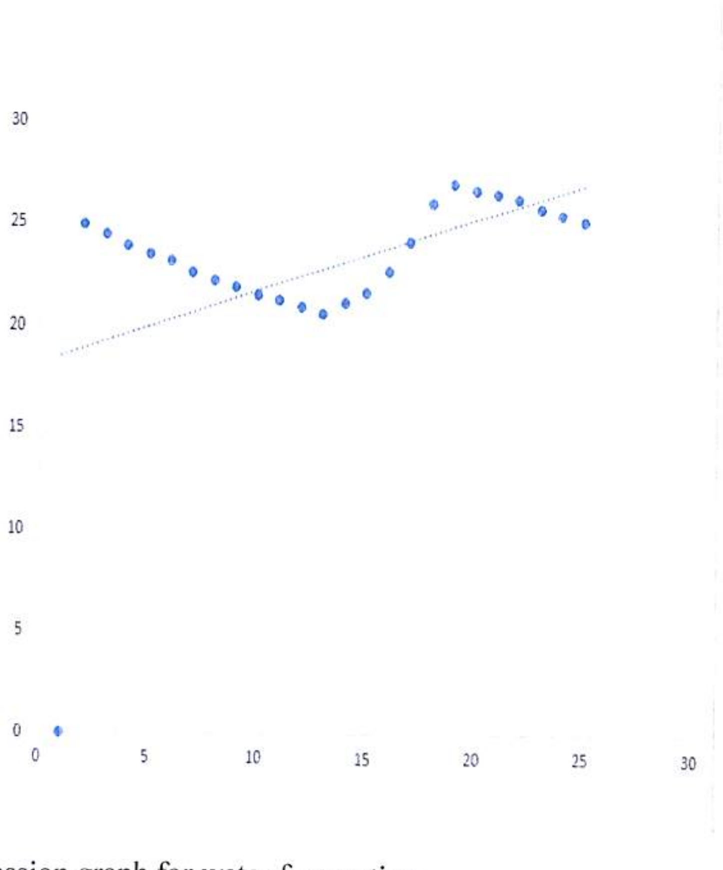
ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	18.71220573	18.71221	5.173382	0.033038498
Residual	22	79.57435677	3.617016		
Total	23	98.2865625			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	29.02355606	2.343779175	12.38323	2.17E-11	24.16285556	33.88425657	24.16285556	33.88425657
Average Temp	-0.326822687	0.143689467	-2.27451	0.033038	-0.624816402	-0.028828972	-0.624816402	-0.028828972

Regression stats for water forecasting using temp variable.

Average Temp	Average Discharge
13.70	24.92
13.43	24.51
13.23	23.90
13.30	23.52
13.23	23.17
12.93	22.67
13.10	22.25
14.57	21.90
16.10	21.55
19.60	21.27
20.57	21.00
19.83	20.63
20.77	21.21
20.20	21.72
19.40	22.75
18.67	24.14
17.70	26.06
16.87	27.00
15.50	26.72
15.17	26.57
15.00	26.34
14.60	25.84
14.57	25.54
14.03	25.21

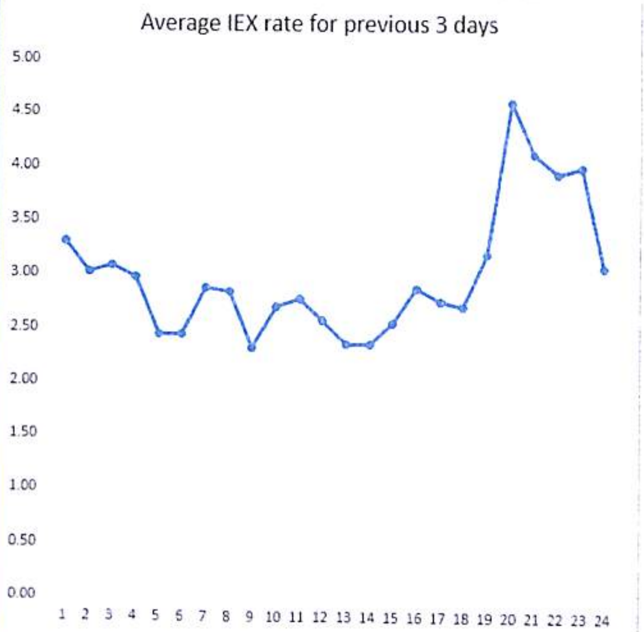


Regression graph for water forecasting

IEX rate forecasting using regression:

IEX rate depends on the time during the day as the power demand increases during peak hours. As per our research model the IEX rate forecasting is done by taking the average of IEX rates of the previous day's data after that the regression analysis is used to forecast IEX rate.

Time	Avg. rate IEX			
	01-Sep-19	02-Sep-19	03-Sep-19	Average IEX Rate
01:00	3.13	3.23	3.57	3.31
02:00	3.12	3.05	2.89	3.02
03:00	3.06	2.99	3.20	3.08
04:00	2.90	2.97	3.05	2.97
05:00	2.51	2.47	2.35	2.44
06:00	2.41	2.39	2.52	2.44
07:00	2.84	2.80	2.97	2.87
08:00	2.81	2.79	2.90	2.83
09:00	2.25	2.29	2.40	2.31
10:00	2.67	2.65	2.78	2.70
11:00	2.69	2.73	2.89	2.77
12:00	2.60	2.63	2.50	2.58
13:00	2.35	2.29	2.43	2.36
14:00	2.25	2.31	2.50	2.35
15:00	2.55	2.49	2.60	2.55
16:00	2.84	2.87	2.90	2.87
17:00	2.78	2.71	2.78	2.75
18:00	2.88	2.78	2.45	2.70
19:00	3.25	3.15	3.20	3.20
20:00	4.57	4.61	4.65	4.61
21:00	4.14	4.10	4.13	4.12
22:00	3.91	3.95	3.97	3.94
23:00	3.97	4.00	4.05	4.01
00:00	3.12	3.10	3.01	3.08



The IEX rate forecasting equation depending on the time

Y (IEX rate) = A+B*X(time), IEX rates Y = 2.3378+0.04950*X(time)

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.541398563
R Square	0.293112404
Adjusted R Squa	0.25945109
Standard Error	0.533662202
Observations	23

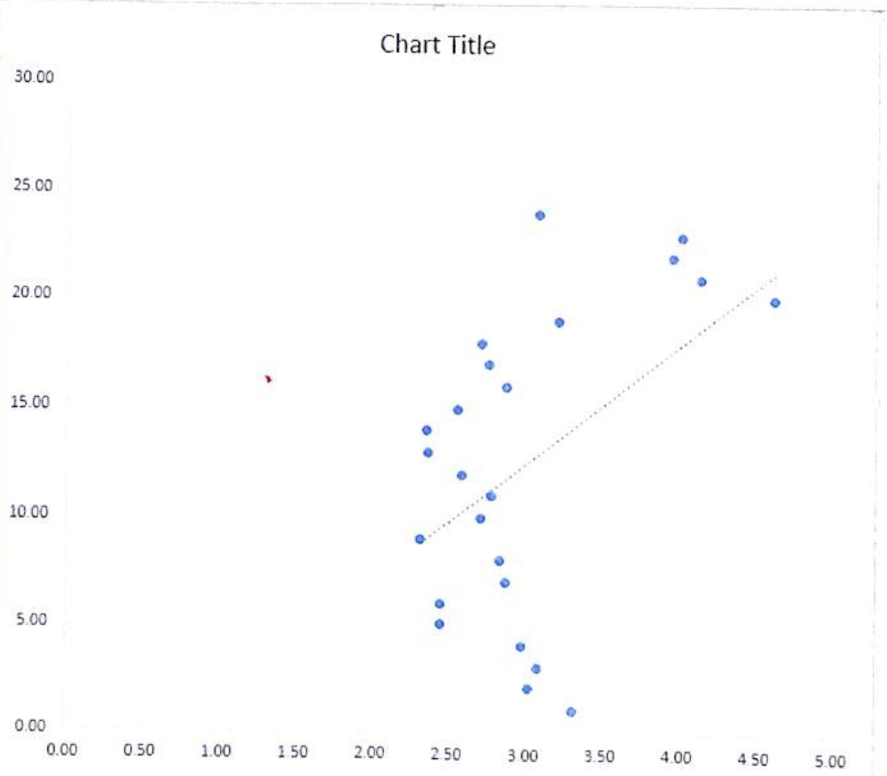
ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	2.479910572	2.479910572	8.70769346	0.007630422
Residual	21	5.980702266	0.284795346		
Total	22	8.460612838			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*Upper 95.0%*
Intercept	2.337850819	0.244830765	9.548844154	4.32105E-09	1.82869737	2.847004267	1.828697	2.847004267
1	0.049502571	0.016775528	2.950880116	0.007630422	0.014615951	0.08438919	0.014616	0.08438919

Regression Stats for IEX rate forecasting

Average IEX Rate	Time
3.31	1.00
3.02	2.00
3.08	3.00
2.97	4.00
2.44	5.00
2.44	6.00
2.87	7.00
2.83	8.00
2.31	9.00
2.70	10.00
2.77	11.00
2.58	12.00
2.36	13.00
2.35	14.00
2.55	15.00
2.87	16.00
2.75	17.00
2.70	18.00
3.20	19.00
4.61	20.00
4.12	21.00
3.94	22.00
4.01	23.00
3.08	24.00



Regression graph for IEX rate forecasting.

Generation schedule according to the discharge and IEX rate forecasting done.

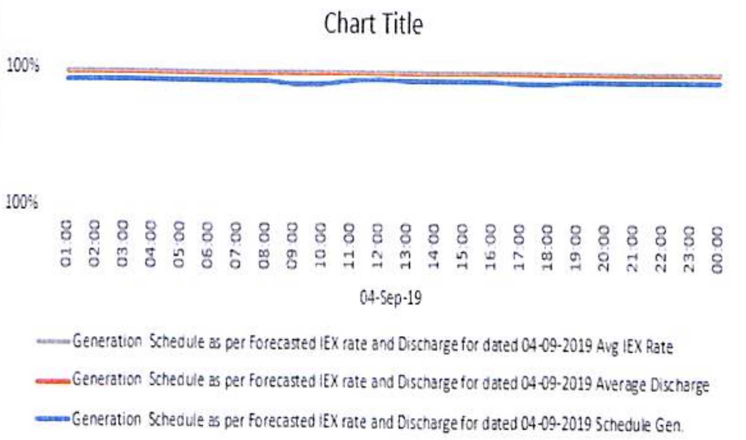
Generation dependent variable depends on IEX rates when discharge is properly managed.

Y=a+bx1 where Y is Scheduled Generation, a and b are constant variable & x1 is IEX rate.

As the discharge remains almost constant for the previous 3 day small variation in the discharge fluctuation can be managed by accumulating or releasing the water through reservoir. Therefore, discharge is not taken as independent variable, only the discharge value is taken as the limitation value for generation i.e. one cumecs discharge is equal to 7 MW with adjustment in load with the stored water.

Generation Schedule as per Forecasted IEX rate and Discharge for dated 04-09-2019

Date	Time	Schedule Gen.	Average Discharge	Avg IEX Rate
04-Sep-19	01:00	180190	24.92	3.31
	02:00	174220	24.51	3.02
	03:00	168240	23.90	3.08
	04:00	168240	23.52	2.97
	05:00	168240	23.17	2.44
	06:00	168240	22.67	2.44
	07:00	168240	22.25	2.87
	08:00	167290	21.90	2.83
	09:00	114710	21.55	2.31
	10:00	114710	21.27	2.7
	11:00	167290	21.00	2.77
	12:00	167290	20.63	2.58
	13:00	167290	21.21	2.36
	14:00	167290	21.72	2.35
	15:00	167290	22.75	2.55
	16:00	167290	24.14	2.87
	17:00	167290	26.06	2.75
	18:00	173020	27.00	2.7
	19:00	186170	26.72	3.2
	20:00	215920	26.57	4.61
	21:00	215920	26.34	4.12
	22:00	195730	25.84	3.94
	23:00	180190	25.54	4.01
	00:00	170630	25.21	3.08



Generation schedule as per forecasted IEX rates and discharge for dated 04-09-2019

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.732370341
R Square	0.536366316
Adjusted R Squar	0.515292057
Standard Error	15598.65678
Observations	24

ANOVA

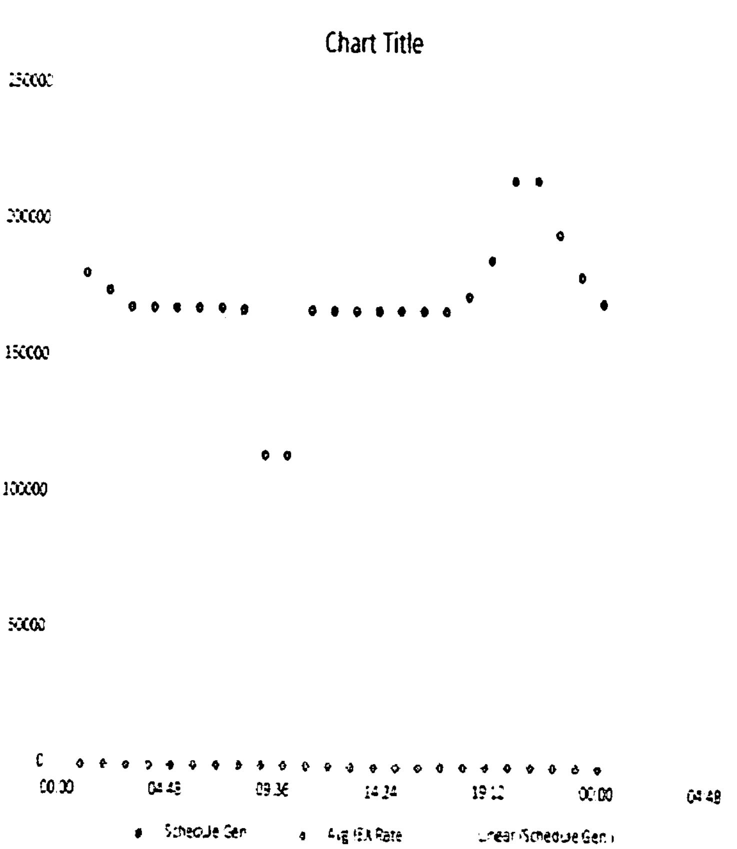
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	6192750743	6.19E+09	25.451255	4.7257E-05
Residual	22	5352998052	2.43E+08		
Total	23	11545748796			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	90394.09496	16266.93575	5.556922	1.384E-05	56658.53501	124129.7	56658.535	124129.6549
Avg IEX Rate	26878.25941	5327.783191	5.044924	4.726E-05	15829.11334	37927.41	15829.1133	37927.40548

Regression Stats

Generation Schedule as per Forecasted IEX rate and Discharge for dated 04-09-2019

Date	Time	Schedule Gen.	Avg IEX Rate
	01:00	180190	3.31
	02:00	174220	3.02
	03:00	168240	3.08
	04:00	168240	2.97
	05:00	168240	2.44
	06:00	168240	2.44
	07:00	168240	2.87
	08:00	167290	2.83
	09:00	114710	2.31
	10:00	114710	2.7
	11:00	167290	2.77
04-Sep-19	12:00	167290	2.58
	13:00	167290	2.36
	14:00	167290	2.35
	15:00	167290	2.55
	16:00	167290	2.87
	17:00	167290	2.75
	18:00	173020	2.7
	19:00	186170	3.2
	20:00	215920	4.61
	21:00	215920	4.12
	22:00	195730	3.94
	23:00	180190	4.01
	00:00	170630	3.08



Regression Graph

Regression equation for generation is Y (gen) = 90394.09+26878.26 *X1(IEX rates)

Therefore we can use the average of IEX rates for 2-3 previous days and generation can be finalized depending on the IEX rates using the regression equation for that particular hour. And accordingly water can be managed to maximize the profit.

Chapter 5

Interpretation of Results

5.1 Interpretation of Results.

Similar day approach used for taking the average of Discharge & IEX rate trends for previous three days after taking the average regression analysis is used on the average data of discharge and IEX rates forecasting the discharge and the IEX rate.

The results we got for discharge forecasting

The water forecasting equation depending on the temperature

Y (discharge) =A+B*X (temp), Y=29.02355+ (-0.3268)*X (temp)

Forecasted Average discharge=22.15 Cumecs

Forecasted Maximum Discharge=24.79 Cumecs

Forecasted Minimum Discharge=22.23 Cumecs

Actual Average Discharge =22.15 Cumecs

Actual Minimum Discharge=18.81 Cumecs

Actual Maximum Discharge=26.70 Cumecs

Discharge forecasting for 04-09-2019 using Regression				
Time	A	B	X(temp)	Y(discharge)
01:00	29.02355	-0.3268	13.7	24.54639
02:00	29.02355	-0.3268	13.43	24.634626
03:00	29.02355	-0.3268	13.23	24.699986
04:00	29.02355	-0.3268	13.3	24.67711
05:00	29.02355	-0.3268	13.23	24.699986
06:00	29.02355	-0.3268	12.93	24.798026
07:00	29.02355	-0.3268	13.1	24.74247
08:00	29.02355	-0.3268	14.57	24.262074
09:00	29.02355	-0.3268	16.1	23.76207
10:00	29.02355	-0.3268	19.6	22.61827
11:00	29.02355	-0.3268	20.57	22.301274
12:00	29.02355	-0.3268	19.83	22.543106
13:00	29.02355	-0.3268	20.77	22.235914
14:00	29.02355	-0.3268	20.2	22.42219
15:00	29.02355	-0.3268	19.4	22.68363
16:00	29.02355	-0.3268	18.67	22.922194
17:00	29.02355	-0.3268	17.7	23.23919
18:00	29.02355	-0.3268	16.87	23.510434
19:00	29.02355	-0.3268	15.5	23.95815
20:00	29.02355	-0.3268	15.17	24.065994
21:00	29.02355	-0.3268	15	24.12155
22:00	29.02355	-0.3268	14.6	24.25227
23:00	29.02355	-0.3268	14.57	24.262074
00:00	29.02355	-0.3268	14.03	24.438546

Forecasting for Discharge for 04-09-2019 on hourly basis.

Similarly for IEX forecasting

The IEX rate forecasting equation depending on the time

Y (IEX rate) =A+B*X (time), IEX rates Y = 2.3378+0.04950*X (time)

Forecasted Average IEX rate= 2.95

Forecasted Maximum IEX rate= 3.52

Forecasted Minimum IEX rate=2.38

Actual Average IEX Rate= 2.98

Actual Maximum IEX Rate=4.57

Actual Minimum IEX Rate= 2.25

IEX rate forecasting for 04-09-2019 using Regression			
A	B	X (Time)	Y(IEX rate)
2.3378	0.0495	1	2.3873
2.3378	0.0495	2	2.4368
2.3378	0.0495	3	2.4863
2.3378	0.0495	4	2.5358
2.3378	0.0495	5	2.5853
2.3378	0.0495	6	2.6348
2.3378	0.0495	7	2.6843
2.3378	0.0495	8	2.7338
2.3378	0.0495	9	2.7833
2.3378	0.0495	10	2.8328
2.3378	0.0495	11	2.8823
2.3378	0.0495	12	2.9318
2.3378	0.0495	13	2.9813
2.3378	0.0495	14	3.0308
2.3378	0.0495	15	3.0803
2.3378	0.0495	16	3.1298
2.3378	0.0495	17	3.1793
2.3378	0.0495	18	3.2288
2.3378	0.0495	19	3.2783
2.3378	0.0495	20	3.3278
2.3378	0.0495	21	3.3773
2.3378	0.0495	22	3.4268
2.3378	0.0495	23	3.4763
2.3378	0.0495	24	3.5258

Forecasting for IEX rate for 04-09-2019 on hourly basis.

5.2 Comparison of Results with Assumptions (Hypotheses)

Actual discharge vs. forecasted discharge for dated 04-09-2019

Discharge forecasting for 04-09-2019 using Regression					Actual discharge on 04-09-2019	Deviation	%age dev
Time	A	B	X(temp)	Y(discharge)			
01:00	29.02355	-0.3268	13.7	24.54639	23.35	-1.20	-4.87
02:00	29.02355	-0.3268	13.43	24.634626	22.41	-2.22	-9.03
03:00	29.02355	-0.3268	13.23	24.699986	21.49	-3.21	-13.00
04:00	29.02355	-0.3268	13.3	24.67711	21.87	-2.81	-11.38
05:00	29.02355	-0.3268	13.23	24.699986	21.39	-3.31	-13.40
06:00	29.02355	-0.3268	12.93	24.798026	21.00	-3.80	-15.32
07:00	29.02355	-0.3268	13.1	24.74247	20.78	-3.96	-16.01
08:00	29.02355	-0.3268	14.57	24.262074	20.46	-3.80	-15.67
09:00	29.02355	-0.3268	16.1	23.76207	19.28	-4.48	-18.86
10:00	29.02355	-0.3268	19.6	22.61827	18.81	-3.81	-16.84
11:00	29.02355	-0.3268	20.57	22.301274	20.65	-1.65	-7.40
12:00	29.02355	-0.3268	19.83	22.543106	20.85	-1.69	-7.51
13:00	29.02355	-0.3268	20.77	22.235914	20.82	-1.42	-6.37
14:00	29.02355	-0.3268	20.2	22.42219	20.37	-2.05	-9.15
15:00	29.02355	-0.3268	19.4	22.68363	20.00	-2.68	-11.83
16:00	29.02355	-0.3268	18.67	22.922194	20.62	-2.30	-10.04
17:00	29.02355	-0.3268	17.7	23.23919	21.52	-1.72	-7.40
18:00	29.02355	-0.3268	16.87	23.510434	22.57	-0.94	-4.00
19:00	29.02355	-0.3268	15.5	23.95815	25.47	1.51	6.29
20:00	29.02355	-0.3268	15.17	24.065994	26.46	2.39	9.94
21:00	29.02355	-0.3268	15	24.12155	26.70	2.58	10.69
22:00	29.02355	-0.3268	14.6	24.25227	26.00	1.75	7.21
23:00	29.02355	-0.3268	14.57	24.262074	25.20	0.94	3.87
00:00	29.02355	-0.3268	14.03	24.438546	23.50	-0.94	-3.84

From the above table the deviation percentage of forecasted discharge vs. actual discharge is maximum 10.69 and minimum is -18.86.

Actual average discharge for the day is 22.15 Cumecs whereas the forecasted discharge was 23.76 Cumecs.

Actual maximum discharge for the day is 26.70 Cumecs whereas the forecasted discharge was 24.79 Cumecs.

Actual minimum discharge for the day is 18.81 Cumecs whereas the forecasted discharge was 22.23 Cumecs

Actual IEX rate vs. forecasted IEX Rate for dated 04-09-2019

IEX rate forecasting for 04-09-2019 using Regression				Actual IEX rate on 04-09-2019	IEX rate deviation	%age dev
A	B	X (Time)	Y(IEX rate)			
2.3378	0.0495	1	2.3873	3.13	0.74	31.1456457
2.3378	0.0495	2	2.4368	3.12	0.68	27.9991177
2.3378	0.0495	3	2.4863	3.06	0.57	23.0713309
2.3378	0.0495	4	2.5358	2.90	0.37	14.5334806
2.3378	0.0495	5	2.5853	2.51	-0.08	-2.9319615
2.3378	0.0495	6	2.6348	2.41	-0.22	-8.4169576
2.3378	0.0495	7	2.6843	2.84	0.16	5.90479827
2.3378	0.0495	8	2.7338	2.81	0.08	2.88865316
2.3378	0.0495	9	2.7833	2.25	-0.53	-19.169331
2.3378	0.0495	10	2.8328	2.67	-0.16	-5.5753142
2.3378	0.0495	11	2.8823	2.69	-0.19	-6.7126947
2.3378	0.0495	12	2.9318	2.60	-0.33	-11.332714
2.3378	0.0495	13	2.9813	2.35	-0.63	-21.187737
2.3378	0.0495	14	3.0308	2.25	-0.78	-25.771001
2.3378	0.0495	15	3.0803	2.55	-0.53	-17.142324
2.3378	0.0495	16	3.1298	2.84	-0.29	-9.1227874
2.3378	0.0495	17	3.1793	2.78	-0.40	-12.688642
2.3378	0.0495	18	3.2288	2.88	-0.35	-10.741529
2.3378	0.0495	19	3.2783	3.25	-0.03	-0.7906537
2.3378	0.0495	20	3.3278	4.57	1.24	37.2943086
2.3378	0.0495	21	3.3773	4.14	0.77	22.6651467
2.3378	0.0495	22	3.4268	3.91	0.48	13.9564608
2.3378	0.0495	23	3.4763	3.97	0.49	14.1191065
2.3378	0.0495	24	3.5258	3.12	-0.41	-11.645513

From the above table the deviation percentage of forecasted IEX rate vs. actual IEX rate is maximum 37.29 and minimum is -25.77.

Actual average IEX rate for the day is Rs. 2.98 whereas the forecasted was Rs. 2.95.

Actual maximum IEX rate for the day is Rs. 4.57 whereas the forecasted Rate was Rs. 3.52.

Actual minimum IEX rate for the day is Rs. 2.25 whereas the forecasted was Rs. 2.38.

Comparison of Actual Generation vs. Forecasted Generation Schedule

Comparision of Actual Generation Schedule vs Forecasted generation

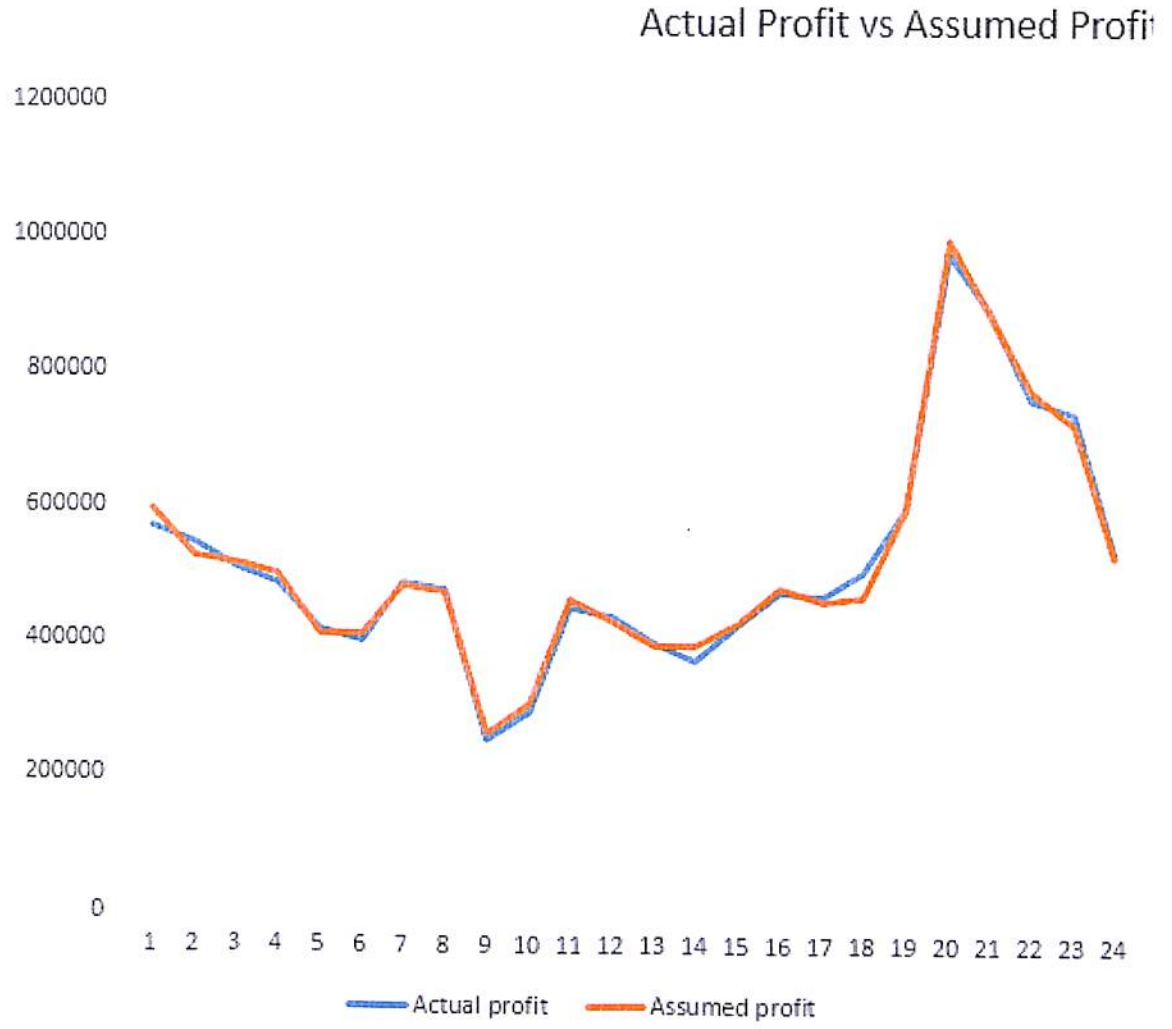
Date	Time	Actual Gen.	Schedule Gen.	Actual Avg. rate IEX	Forecasted IEX Rate	Generation Deviation	IEX rates deviation	Usable discharge	Actual profit	Assumed profit
04-Sep-19	01:00	182000	180190	3.13	3.31	1810	-0.18	23.35	569812.9	596428.9
	02:00	175021	174220	3.12	3.02	801	0.10	22.41	545904.9	526144.4
	03:00	167230	168240	3.06	3.08	-1010	-0.02	21.49	511710.8	518179.2
	04:00	167300	168240	2.90	2.97	-940	-0.07	21.87	485896.1	499672.8
	05:00	167020	168240	2.51	2.44	-1220	0.07	21.39	419136.7	410505.6
	06:00	166810	168240	2.41	2.44	-1430	-0.03	21.00	402517.5	410505.6
	07:00	171850	168240	2.84	2.87	3610	-0.03	20.78	488535.6	482848.8
	08:00	169470	167290	2.81	2.83	2180	-0.02	20.46	476680.1	473430.7
	09:00	113610	114710	2.25	2.31	-1100	-0.06	19.28	255595.2	264980.1
	10:00	110740	114710	2.67	2.7	-3970	-0.03	18.81	296214.3	309717
	11:00	167230	167290	2.69	2.77	-60	-0.08	20.65	449651.4	463393.3
	12:00	168912	167290	2.60	2.58	1622	0.02	20.85	439094.8	431608.2
	13:00	170000	167290	2.35	2.36	2710	-0.01	20.82	399437.1	394804.4
	14:00	164430	167290	2.25	2.35	-2860	-0.10	20.37	369923.5	393131.5
	15:00	166254	167290	2.55	2.55	-1036	0.00	20.00	424324.3	426589.5
	16:00	166810	167290	2.84	2.87	-480	-0.03	20.62	474453.5	480122.3
	17:00	169003	167290	2.78	2.75	1713	0.03	21.52	469133.7	460047.5
	18:00	175254	173020	2.88	2.7	2234	0.18	22.57	505078.1	467154
	19:00	183024	186170	3.25	3.2	-3146	0.05	25.47	595263.6	595744
	20:00	213320	215920	4.57	4.61	-2600	-0.04	26.46	974633.5	995391.2
	21:00	214842	215920	4.14	4.12	-1078	0.02	26.70	890041	889590.4
	22:00	194000	195730	3.91	3.94	-1730	-0.03	26.00	757581.6	771176.2
	23:00	186480	180190	3.97	4.01	6290	-0.04	25.20	739789	722561.9
	00:00	171652	170630	3.12	3.08	1022	0.04	23.50	534730.7	525540.4

Actual average Generation for the day is 170927.5833 Units/hour whereas the scheduled generation was 170872.0833 Units/hour

Actual total generation for the day is 4102262 Units whereas the scheduled generation was 4100930 Units

Actual maximum generation for the day is 214842 Units/hour whereas the scheduled generation was 215920 Units/hour

Actual minimum generation for the day is 110740 Units/hour whereas the scheduled generation was 114710 Units/hour



Actual total profit for the day is Rs. 12475140 whereas the assumed profit as per forecasting was Rs.12509267.

In the results above, the deviation in the actual generation to schedule generation is within DSM regulation with proper management of water and proper scheduling considering the facts such as discharge and IEX rates.

Chapter 6

Conclusion and scope for future work

Accurate load forecasting is very important for electric utilities in a competitive environment created by the electric industry deregulation. In this paper we reviewed statistical techniques and that are used for electric load forecasting. We also discussed factors that affect the accuracy of the forecasts such as weather data, time factors and IEX rates. Load forecasting methods use advanced mathematical modelling. Additional progress in load forecasting and its use in industrial applications can be achieved by providing short-term load forecasts in the form of probability distributions rather than the forecasted numbers; for example the so-called ensemble approach can be used. We believe that the progress in load forecasting will be achieved in two directions: (i) basic research in statistics and artificial intelligence and (ii) better understanding of the load dynamics and its statistical properties to implement appropriate models.

Different strategy need to be followed on different days depending upon the similar day approach. Proper scientific approach strategy can optimize the operational profitability. In DSM regulation flexibility should be there for hydro plants as during surplus discharge, excess water is spilled which is a national loss as the running cost of hydro plants is negligible. No penalties should be imposed for over injection during surplus flow of discharge in the stream.

Hydrology algorithm for proper discharge forecasting considering all the factors which affect the discharge of that particular area. In regard to selling of power a comparative study should be done for opting PPA or open access as the grid regulations are becoming stringent day by day.

The flexibility of revision of schedule is not possible in open assess as in PPA for hydro plants revision of schedule should be amended as the water in the stream sometime fluctuates on regular basis due to sudden flash flooding in the catchment area.

Scope for future work

In this case study we have discussed several statistical techniques that have been developed for short-term electric load, IEX rates and discharge forecasting. Several statistical models and algorithms that have been developed though, are operating ad hoc. The accuracy of the forecasts could be improved, if one would study these statistical models and develop mathematical theory that explains the convergence of these algorithms.

Researchers should also investigate the boundaries of applicability of the developed models and algorithms. So far, there is no single model or algorithm that is superior for all utilities. The reason is that utility service areas vary in differing mixtures of industrial, commercial and residential customers. They also vary in geographic, climatologic, economic and social characteristics. Selecting the most suitable algorithm by a utility can be done by testing the algorithms on real data. In fact, some utility companies use several load forecasting methods in parallel. As far as we know, nothing is known on a prior conditions that could detect which forecasting method is more suitable for a given load area. An important question is to investigate the sensitivity of the load forecasting algorithms and models to the number of customers, characteristics of the area, energy prices, and other factors.

As mentioned above, weather is an important factor that influences the load. The usual approach to short-term load forecasting uses the forecasted weather scenario as an input. However, one of the most important recent developments in weather forecasting is the so called ensemble approach which consists of computing multiple forecasts. Then probability weights can be assigned to these ensembles.

Instead of using the single weather forecast, weather ensemble predictions can be used as multiple inputs for load forecasts. These inputs generate multiple load forecasts. There are two advantages of having load forecasts in the probabilistic form: (i) they can lead to a more accurate hourly forecast obtained by using multiple ensembles, for example, by averaging them; (ii) the probabilistic description of the future load can be used as an input to decision support systems to make important generation, purchasing and switching decisions. In general, it is known from the appropriate mathematical models that the knowledge of the demand distribution leads to more cost efficient decisions than the knowledge of the expected demand. On a broader scale, we think that the important research and development directions are: (i) combining weather and load forecasting and (ii) incorporating load forecasting into various decision support systems.

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