Decentralized Interchange Scheduling in India

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***Abstract*—The paper presents a review of the decentralized interchange scheduling and despatch mechanism for Inter-State transactions in electricity as implemented in India. It elaborates the mechanisms adopted to address the fundamental power system problems of Unit commitment, Economic Dispatch and Generation Control of shared generation resources within the federal governance structure in India. The authors derive learning from the experience at the inter-state level and recommend implementation of the similar mechanism within the intra-State system for realizing the objective of economic and efficient operation of the electricity market in India. The paper also discusses the emerging challenges in Interchange Scheduling with the increasing number and volume of short-term open access transactions, envisaged integration of large scale Renewable Energy Sources and growing aspiration of market players in India.**

Keywords—access; ancillary; balancing; congestion; contracts; decentralized; dispatching; economy; interchange; scheduling; security; settlement

I. INTRODUCTION

India has adopted a federal structure of governance. The Scheduling and dispatching of the intra-state generating stations (wholly owned or having purchase agreements of more than 50 % of the Installed capacity), are coordinated by the respective State Load Despatch Centres while the coordination for the inter-state generation stations or ISGS (contracted by utilities of more than one State) is done by the Regional Load Despatch Centre. The Availability Based Tariff (ABT) for ISGS and Unscheduled Mechanism (UI) for settlement of Interchange transactions at interstate level commenced in the five Regional Grids of India in a phased manner after the notification of the order in January 2000 by the Central Electricity Regulatory Commission. The conceptual background is elaborated in [1] and [2]. This was a major reform which established the fundamental building block of the Electricity Market in India. This paper presents a review of the decentralized interchange scheduling and despatch mechanism for Inter-State transactions in electricity as implemented in India.

II. GENERIC MODELS OF SCHEDULING AND DESPATCHING

Scheduling is described as the assignment of generation to meet anticipated demand [3]. Unit commitment, Economic Dispatch and Generation Control are the three activities involved in generation scheduling. Different models of scheduling and dispatching are documented in literature. Sally Hunt [4] classified the models into two categories- Integrated (Centralized) and De-centralized. The key difference between the two extracted from [4] is quoted below.

"*The essential difference between integration and decentralization is whether or not the system operator administers a spot market integrated with the pricing of imbalances, congestion management, and the ancillary services. The integrated model says the system operator should run the spot market, integrated with imbalances, and the others, because he will anyway be doing something very similar, and we might as well accept this and make it work efficiently. The decentralized model attempts to keep the spot market separate from the system operator, to be organized off-line by traders, as in the wheeling model…The system operator is not intended to facilitate a spot market – he simply schedules trades that have been arranged elsewhere*."

Felix F. Wu and Pravin Varaiya [5] proposed the coordinated multilateral trading model for "*a restructured industry that encourages efficient competition and at the same time maintains necessary coordination to guarantee a high standard of reliability.'* In this model, *"the decision mechanisms regarding economics and reliability (security) of system operation are separated. Economic decisions are carried out by private multilateral trades among generators and consumers. The function of reliability is coordinated through the power system operator who provides publicly accessible data based upon which generators and consumers can determine profitable trades that meet the secure transmission loading limits."*

III. SCHEDULING AND DESPATCHING MODEL IN INDIA

The Electricity Act [6] mandates that the Regional Load Despatch Centre (RLDC) shall be responsible for optimum scheduling and despatch of electricity within the region, in accordance with the contracts entered into with the licensees or the generating companies operating in the region. It further mandates the RLDCs to keep account of the electricity flowing through the regional grid.

The five Regional grids in India are operated as power pools with decentralized scheduling and despatch. The system of each regional entity is treated and operated as a notional control area. The algebraic summation of scheduled drawal from Inter State Generating Stations (ISGS) and other bilateral/collective transactions provides the drawal schedule of each regional entity, and this is determined in advance on day-ahead basis.

Regional Entity Buyers have operational autonomy and total responsibility for (i) scheduling / dispatching their own generation (including generation of their embedded licensees); (ii) regulating the demand of its control area; (iii) scheduling their drawal from the Inter State Generating Stations (within their share in the respective plant's expected capability); (iv) permitting long term access, medium term and short term open access transactions for embedded generators/consumers, in accordance with the contracts; and (v) regulating the net drawal of their control area from the regional grid in accordance with the respective regulations of the CERC [7].

The distribution utilities in various States enter into bilateral power purchase agreements with the Inter State Generating Stations and approach the RLDCs to schedule these transactions. The time-line and procedure for coordinating the scheduling of Inter State Generating Stations is elaborated in the Indian Electricity Grid Code. ISGS having two part tariff, declare the station ex-bus capacity in the 96 time blocks for the next day. Entitlement of the beneficiaries/procurers in the declared capacity of the station is computed from the % share of drawee entities in the station capacity as per the power purchase agreements. Beneficiaries / procurers assess their anticipated demand as well as the available resources and submit their requisitions within the entitlement along with the other approved applications for short-term transactions [7].

The utilities also have the option to sell-purchase electricity through bilateral short-term market or from the independent Power Exchange. The Power Exchange is neither owned nor operated by the RLDC/NLDC. The power exchanges conduct the day-ahead electronic auctions (closed, double-sided) and submit the net position of the regional entities at the interstate periphery to NLDC. While arriving at the market clearing volume, the available transfer capability margins assessed by the NLDC are duly accounted for by the power exchanges.

With these inputs, the RLDCs prepare the Interchange Schedules (ex-bus injection schedule for the ISGS and the drawal schedule of the beneficiaries/regional entities at the respective periphery) for all regional entities within its jurisdiction. While doing so the RLDCs check the network transfer capability and validate the feasibility of transactions. In case of transmission constraints the schedules are curtailed suitably.

TABLE 1. TYPICAL TRANSFER CAPABILITY ASSESSED BY RLDCS/NLDC

Corridor	Total Transfer Capability	Reliability Margin	Available Transfer Capability for interstate transactions
WR to NR	10050	500	9550
ER to NR	4500	300	4200
WR to SR	4700	500	4200
ER to SR	3750	250	3500
NER to ER	1330	45	1285
ER to NER	1100	45	1045

Thus the economic decisions are taken by the market players while the system operator takes care of the system security. It may be inferred from the above that the model adopted in India has the characteristics of the decentralized model described in [4] and the coordinated multilateral trading model described in [5]. The sections ahead further elaborate the various facets of the scheduling mechanism implemented in India.

A. Registered Users

The Indian grid is demarcated into five regional grids. The regional entities have to register (as a User) with the RLDC of the region in which they are geographically located. The scheduling and metering of the registered users is coordinated by the RLDCs. There are around 161 such rregional entities. This includes 109 generating stations and 52 buyers. Procurement of generation capacity is through competitive bidding.

B. Type of Access for scheduling electricity transactions

Scheduling of transactions at interstate level can be commenced only after getting access to the interstate grid. Access to the grid could be of three types- long-term, medium term or short term. Long-term Access (LTA) is for use of the inter-State Transmission system for a period exceeding seven (7) years. Medium-term Open Access (MTOA) is for use the inter-State Transmission system for a period equal to or exceeding three months but not exceeding five years [8]. Short term Open Access (STOA) can be for one month at a stretch for a delivery date falling in the third month from the month of application [9]. There is a provision for day-ahead STOA through the Power Exchange [10]. The Central Transmission Utility (CTU) grants the long-term access while the short-term access for interstate transactions is granted by the RLDC of the region where the drawal point is located. The network transfer capability is assessed by the CTU/RLDCs/SLDC as per the CERC approved regulations/procedures [11].

Presently scheduling of more 145 long-term power purchase agreements are being coordinated at the interstate level. Out of this, 81 involve Central Generating Stations, 12 involves Ultra Mega Power Plants and 52 are others. Thus, the aggregate generation capacity whose scheduling is coordinated and settled by RLDCs is around 80,000 MW. This includes 69357 MW of Central Generating Stations, 6378 MW of the Ultra Mega Power Producers and 2241 MW of Medium Term Open Access granted to utilities.

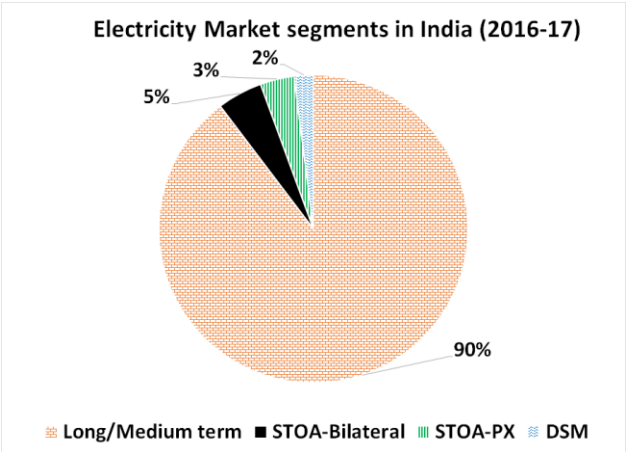

Fig. 1. Electricity Market share of various segments in 2016-17

The long-term and medium-term contracts have two part tariff with Capacity and Energy Charges while the Short-term contracts are energy only contracts. In 2016-17, the total generation was 1157 BU. 90% of this energy was scheduled under long/medium transactions while the % share of short-term bilateral, short-term collective (PX) and Unscheduled Interchange was 5%, 3% and 2% respectively. The total size of the short-term market was Rs. 22,124 Crore [12].

C. Schedules as deemed contracts

Interchange scheduling is coordinated on a day-ahead basis with a settlement period of 15-minutes. Thus, there are 96 time block in a day for which schedules have to be prepared. The interchange schedule of the generating station at its interface with grid is known as the "Injection Schedule" while the interchange schedule of a drawee entity at its periphery is known as "Drawal Schedule".

The schedule in a particular time block is a deemed contract. Assuming that the number of long term plus medium term transactions are 200 in number, the number of contracts would be 70,08,000 (200 x 96 x 365) long-term/medium term contracts. Apart from these, there are typically 12,000 Short-term Bilateral transactions (Advance, Day-ahead, Intra-day Contingency) that are scheduled in one or more of the 96x365 time blocks in a year which would add up to 42,04,80,000 short-term contracts. Thus the scheduling coordinators at the five RLDCs collectively handle around 43 crore contracts annually.

D. Decentralized thermal unit commitment

Eric Hirst [13] defines Unit commitment as "*the process a utility goes through in deciding which units to operate the following day, and when to turn these units on and off. Such a process is necessary because electricity use varies throughout the day, often by a factor of two or more. This variation in electricity use argues for the operation of different units at different times during the day to minimize the overall costs of electricity production.*"

Wood and Wollenberg [14] explain that the question that is answered through unit commitment is *"Given that there are a number of subsets of the complete set of N generating units that would satisfy the expected demand, which of these subsets should be used in order to provide the minimum operating cost?"*

In India, the State entities anticipate their demand for the next day and stack the resources under their disposal as per merit order. They submit their requisitions in the ISGS for every 15-min time block of the next day. Thereafter the injection schedule of the station is computed by aggregating the requisitions received from its procurers. If the aggregate requisition is less than 55% of the Installed Capacity less normative auxiliary consumption of the station, then the ISGS may approach the RLDC to moderate the interchange schedule. In such cases, the RLDCs may consider to moderate the requisitions upwards (to ensure Injection Schedule up to the technical minimum level of the station) if the grid conditions so demands. Else, the injection schedule may be issued without any moderation. In such cases, the Generating Station has the discretion to decide the number of units it would like to keep on bar to deliver up to the injection schedule.

The thermal units kept off-bar due to low requisition by the procurers are considered to be under Reserve Shut Down (RSD). During such time, the Station declares two sets of capacity-On Bar DC and Off-bar DC. One or more procurers may request the generating station to bring additional unit on bar (with mutually agreed lead-time) by giving a commitment of assured requisition up to the technical minimum level from the station for a mutually agreed time duration. There is a mechanism to commercially compensate the thermal stations for loss in heat rate and increased auxiliary compensation for partial loading. Likewise, the start-up costs beyond seven (7) restarts after RSD are to be shared by the entities who under-requisitioned.

TABLE 2. NUMBER OF RESERVE SHUT DOWNS IN TWO OF THE ISGS

Thermal Station	No. of RSD in 2016-17
Mouda Unit #1	13
Mouda Unit #2	9
Vindhyachal Unit #5	9
Vindhyachal Unit #6	7
Mouda Unit #3	5
Vindhyachal Unit # 3	5
Vindhyachal Unit #4	4
Vindhyachal Unit #2	4
Vindhyachal Unit #1	3
Vindhyachal Unit #7	3
Vindhyachal Unit #10	2
Vindhyachal Unit #11	2
Vindhyachal Unit #12	2
Vindhyachal Unit #8	1
Vindhyachal Unit #9	1

The unit commitment problem for the ISGS is addressed in a decentralized manner at the interstate level in an oblique way. The mechanism has significantly improved load-generation balance under short-term surplus. However an elaborate algorithm that considers the regional demand forecast, mandated reserve requirements as well as the thermal generation constraints (start-up time, ramping) needs to be evolved.

E. Decentralized Hydro unit commitment and scheduling

The Inter State Hydro Generating Stations declare the anticipated energy for the next day based on the anticipated inflows, reservoir level and commitment for water releases to meet riparian, irrigation, drinking water, flood control and other requirements. In addition to the energy, the hydro stations also declare the maximum power in MW that it could generate for at least three hours with the available reservoir level and units. Since the hydro generation has the status of must-run, the beneficiaries of the station submit the requisition

to indicate their peaking requirements while honoring their energy entitlement for the day. The moderated injection schedules are issued by the RLDCs within the hydrological constraints with adequate number of units on bar and loaded at efficient level to meet the regional peaking requirement. The mechanism has been found to be effective in extracted the flexibility services of the energy limited hydro resources at the interstate level and efforts are being made to implement it at the intrastate level as well [15].

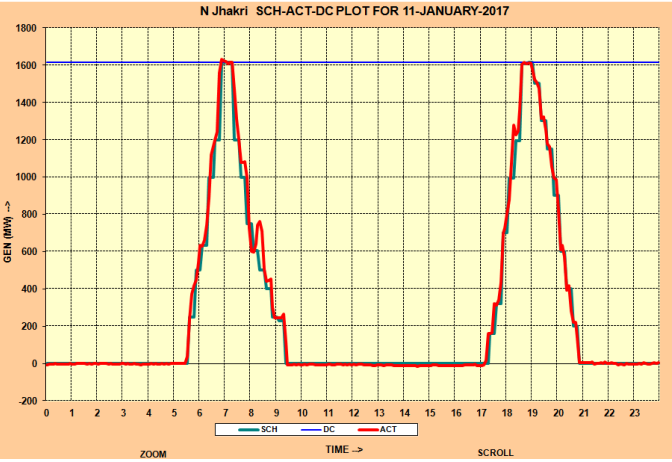

Fig. 2. Peaking support from a typical ISGS Hydro

F. RES scheduling

As per IEGC, all renewable energy power plants, except for biomass power plants, and non-fossil fuel based cogeneration plants whose tariff is determined by the CERC are treated as 'MUST RUN' power plants and are not be subjected to 'merit order despatch' principles. The wind and solar generators, which are regional entities, forecast their generation at each 15-min interval. The schedule can be revised with an hour notice subject to maximum 16 revisions in a day. The IEGC mandates declaration of the Available Capacity by the RES.

G. Decentralized despatch

Subject to the transmission constraints, deviations from schedule in a time block are permitted within the limits specified in the Deviation Settlement Mechanism Regulations notified by the CERC. The regional entities are further mandated to ensure reversal of sign of deviation from schedule at least once in every twelve time-blocks (of 15-min each). This implies that a regional entity that is over injecting continuously for the last twelve time blocks is mandated to under inject in the thirteenth time block else it is treated as a violation.

In order to maintain the actual interchange with the regional grid close to the respective interchange schedule, the regional entities have the choice to regulate their internal generation and/or consumers' load or revise their requisitions within their entitlement in the scheduled long-term / medium term contracts with the Inter State Generating Stations. The grid code permits revision of interchange schedules pertaining to long-term and medium term contracts with advance intimation of at least an hour to the concerned RLDC. Such revisions could be requested by the buyer or the seller and they would be effective from a prospective time. This provision enables the load serving regional entities to dispatch generation in a decentralized manner to take care of the forecast errors or contingencies within their control area.

The option to revise their requisitions to control their deviations from schedule is extensively exercised by the drawee entities. However owing to the large forecast errors and absence of adequate spinning reserves the deviations from schedule are significantly high. Table 3 [Source: wrldc.org] presents the typical statistics for entities in Western Region. This indicates that there is a huge scope for improvement by deployment of advanced demand/RES forecast algorithms and maintaining reserves. Suitable mechanism for faster scheduling could also be explored to facilitate disposal of near-real time surplus/deficits.

TABLE 3. COMPLIANCE TO DEVIATION REGULATIONS IN 2016-17

WR-Regional Drawee Entity	**Compliance to deviation Volume limit (% time)**	**Compliance to reversal of deviation polarity after 12 time blocks (% time)**
Maharashtra	63	85
Madhya Pradesh	73	79
Gujarat	70	82
Chhattisgarh	50	70
Goa	63	43
Daman and Diu	87	44
Dadar Nagar Haveli	99	61
Essar Steel	44	96

The provision of revision also facilitate optimization of the generation in real-time. The IEGC empowers the RLDCs to suo motu revise the interchange schedule in the interest of better system operation or during transmission constraints. Short-term schedules have to be curtailed before the medium term and long-term schedules. Curtailment of transactions scheduled through PX are practically difficult.

H. Despatch of Un-requisitioned surplus

The difference between the Declared Capacity of the station and aggregate requisition by its beneficiaries (buyers) is termed as un-requisitioned surplus. All generating companies whose tariff is determined by CERC under section 62 or adopted by the CERC under section 63 of the Act are permitted to revise their schedule for Un requisitioned Surplus (URS) power from one beneficiary to another beneficiary of the same power station within 4 time blocks with the consent of the both beneficiaries and is treated as temporary re-allocation. It is a kind of intra-day bilateral trade of energy between co-beneficiaries of a Station that involves transfer of liability of payment of fixed charges only for a few time blocks. The generating station may also sell the URS in their station after taking No-objection certificate from the original beneficiary. Such sale could be either through the Power Exchange (Collective Transaction) or through Bilateral

STOA. The left-over URS in a station can further be suo motu despatched by the RLDC to one/more beneficiary of that station for better system operation. It could also be despatched under ancillary services by NLDC for system balancing or congestion alleviation.

I. Balancing through Ancillary Services

CERC vide its suo motu order [16] mandated keeping secondary reserves at the regional level equivalent to the size of the largest unit in the region. It also mandated keeping tertiary reserves in the State grid equivalent to the half the size of size of largest unit in the State grid.

TABLE 4. QUANTUM OF RESERVES TO BE MAINTAINED

	Region	Envisaged quantum of Secondary Reserve	Envisaged quantum of Tertiary Reserves
1	North	800 MW	1658 MW
2	West	800 MW	1353 MW
3	South	1000 MW	1343 MW
4	East	660 MW	857 MW
5	North-east	363 MW	65 MW
	Total	3623 MW	5218 MW

The commercial mechanism for maintaining reserves is being evolved. However at the regional level, the aggregate quantum of un-dispatched power (out of units on bar) with RRAS service providers is monitored. Utilities are advised to bring additional units on bar, in case of the reserves at the interstate level are below the mandated levels.

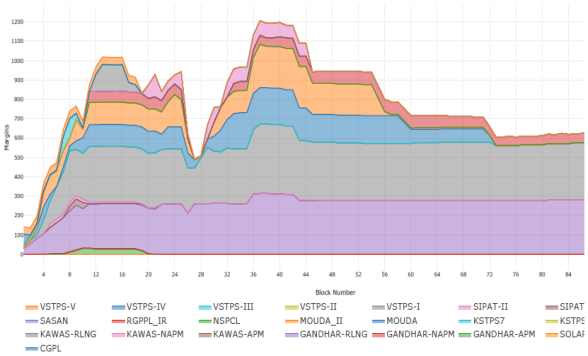

Figure 3: Typical plot of available reserves in WR on a typical day

J. Automatic Generation Control

A pilot project for implementing secondary control through Automatic Generation Control (AGC) was started on 29th June 2017. To start with 2x500 MW Dadri Thermal Power Station Stage-II has been wired to receive AGC signals from NLDC control room for regulation up to +/- 50 MW based on the Area Control Error of Northern Region. Load ramp of 10 MW/min has been considered. The maximum difference between two successive values of Delta P is considered as 1 MW. The quantum of Delta P received through the AGC is aggregated for every time block and algebraically added to the despatch schedule derived from the beneficiaries of power station. AGC is envisaged to be rolled out after approval of the terms of compensation for the power stations participating in the mechanism.

K. Despatching Ancillary Services

CERC notified the regulations for Ancillary Services on 19th August 2015. These regulations [17] are applicable to regional entity generating station and it outlines a framework for both Regulation Up and Regulation Down service by Reserves Regulation Ancillary Services (RRAS) providers. The implementation commenced w.e.f 12th April 2016. NLDC operating as the nodal agency, call for these services in varying situations. Typical number of RRAS instructions issued in the first six months of its implementation is given in Table 5.

TABLE 5. TRIGGERING CRITERIA FOR RRAS IN APR-SEP-16

Triggering Criteria	RRAS up	RRAS down	Total
Extreme weather	13	81	94
Tripping	28	4	32
Trend of load met	386	9	395
Trend of net load met	43	1	44
Trend of frequency	108	52	160
Loop flow/congestion	7	3	10
Line loading control	2	0	2
High frequency	0	44	44
Low frequency	29	0	29
Voltage control	0	1	1
Others	258	4	262
Multiple reasons	114	21	135
Total	988	220	1208

There are 50 Ancillary Service Providers with an installed capacity of around 52 GW. NLDC is the nodal agency for despatch through RRAS. Based on the pre-declared variable energy rate, merit order stack of the available Un-requisitioned Surplus (URS) power available with RRAS service providers is prepared by NLDC. Dispatch instruction for regulation-up or regulation down is issued to the RRAS service provider by NLDC through the RLDCs who incorporate the regulation quantum and issue a revised injection schedule. For up-regulation, power is scheduled from the generator (source) to the Virtual Ancillary Entity or VAE (sink) by the concerned RLDC. Similarly, for down regulation, power would be scheduled from the VAE (source) to the generator (Sink), so that effective scheduled injection of the generator comes down. With this arrangement the original requisition of the beneficiaries of the RRAS provider remains unchanged [18]. The RRAS providers are paid from the Regional DSM Pool account.

During the 2016-17, total 1917 number of instructions for RRAS-up amounting to 2277 MU and 373 number of instructions for RRAS down amounting to 308 MU were issued by NLDC. Highest RRAS up on a particular day was 3746 MW while the highest RRAS down on a particular day was 1946 MW [18].

The ancillary services (fast tertiary) has been implemented in India without any additional CAPEX. The residual un-dispatched surplus in the CERC regulated Inter State Generating Stations is despatched by NLDC/RLDC without encroaching the freedom and choice of the State entities to schedule their entitled share in the above stations. Thus the Ancillary Services implemented in India is a thin layer of centralized despatch within the decentralized framework [18].

Presently only the CERC regulated generators are being dispatched by the System Operators under the RRAS. There is a need to expand this mechanism and evolve the ancillary market to include the Independent Power Producers also.

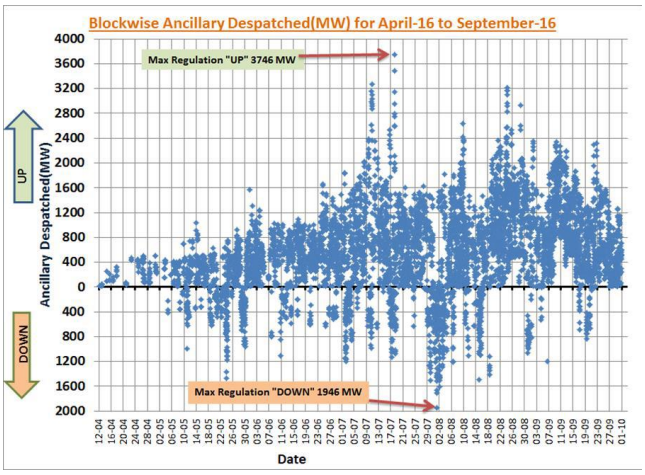

Figure 4. Quantum of Ancillary despatched in Apr-Sep 16

L. *Honouring Ramping Constraints*

The IEGC mandates that the generating stations shall also declare the possible ramping up / ramping down in a block. Typical constraints submitted by coal fired stations is given in Table 6. While issuing the final injection schedule the, RLDCs ensure that the ramping constraints are honored by suitably moderating the long-term requisitions. However challenges are often faced in moderation when the proportion of long-term requisitions of a particular entity is small as compared to its short term schedules.

Further for development of the ancillary market and for meeting the ramping challenges posed by the large scale integration of solar generating in the grid, there is a need to benchmark the ramping capabilities of the generating units. For instance it is observed that the ramp rates (in per minute) of the thermal units submitted by the generating stations is in the range of 0.24 % to 0.46 % of its installed capacity [http://www.wrpc.gov.in/Commercial_rras_dat.asp] which appears fairly conservative.

TABLE 6. TYPICAL THERMAL GENERATION CONSTRAINTS

Name	Unit size (MW)	Ramp up rate MW/min	Ramp down rate MW/min	Cold start in min	Warm start in min
Vindhyachal	210	1.0	1.0	300	180
Sipat	500	2.3	2.3	420	330
Sasan	660	2.0	2.0	600	480
Mundra	830	2.0	2.0	4320	

M. *Scheduling of Transmission Losses*

Transmission Losses are settled in kind. Point of Connection (PoC) injection loss and PoC withdrawal loss for scheduling interstate is applied while scheduling transactions between Designated ISTS customers (DICs).

Simulations studies are conducted on a quarterly basis to place all the DICs in one of the nine slabs for transmission losses [19]. The loss percentage is graded in steps of 0.25 percentage points around the 5th slab (normal slab). The losses are recovered equally from the injecting as well drawee entity. The transmission loss for the 5th slab for the week 'w' is taken as half of the average metered regional transmission loss computed in the week 'w-2'.

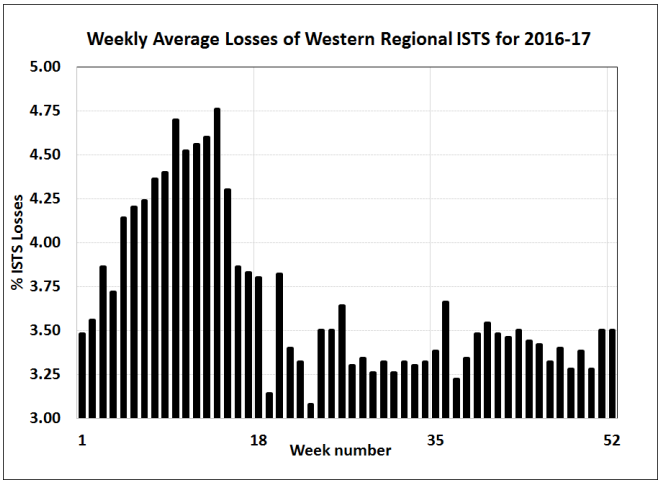

Figure 5. Average WR-ISTS losses for 2016-17 [www.wrldc.org]

The drawal schedule of a long-term transaction is computed after applying the PoC injection as well as withdrawal loss on the ex-bus injection schedule of the generator. Thus, the transmission losses for long-term and medium term transactions is borne by the drawee entity. While in case of the STOA, the approved quantum is jacked up by the appropriate injection PoC loss to arrive at the injection schedule for the injecting utility. For the drawee entity the drawal schedule is computed after deducting the appropriate withdrawal PoC loss. Solar transactions are exempted from ISTS losses.

N. *Congestion Management*

Network Transfer capability check precedes scheduling of transactions by the RLDCs. The network transfer capability for the commercial transactions is assessed by the NLDC in consultation with the RLDCs. These are based on the anticipated network topology and load generation balance in the grid for the period of assessment. The transfer capability for various inter regional corridors is declared three months ahead and posted on the website. In case of major changes in network or load-generation balance, the capability is revised and uploaded on the website. The Available Transfer Capability (ATC) for scheduling collective transactions is assessed on day-ahead basis.

The long-term and medium term contracts have a higher priority of scheduling as compared to the short-term contracts. STOA is facilitated within the margins available in the network. Financial Transmission Rights are not mandated however 'congestion management' for bilateral Short term Open Access Customers (Three-month advance, Month Ahead) across an interface is through e-auction. In case of day-ahead collective short-term congestion management is through market splitting [10]. The transactions of winning bidders are scheduled.

If congestion is experienced during real-time, the scheduled transactions are curtailed to relieve the constraints. The STOA-bilateral transactions are the first to be curtailed followed by MTOA and LTA transactions. RLDCs curtail a transaction at the periphery of the Regional Entities. SLDC(s) shall further incorporate the inter-se curtailment of intra-State Entities to implement the curtailment.

O. Scheduling of international contracts

Indian grid is interconnected with the grids of Bhutan, Nepal and Bangladesh. Cross border trade of electricity has been taking place under bilateral Memorandum of Understanding. Scheduling of such international contracts is coordinated by the National Load Despatch Centre. The energy exchanges within the SAARC countries is expected to increase further after the signing of the SAARC Frame Work Agreement for Energy Cooperation (Electricity) in November 2014. In order to facilitate the same, the Ministry of Power, Govt. of India issued "Guidelines on Cross Border Trade of Electricity" in December 2016 [19]. CERC has also notified draft regulations on "Cross Border Trade of Electricity" in Feb 2014 [20].

P. Schedule reconciliation and Implemented Schedule

After the operating day is over at 2400 hours, all the scheduled interchanges are posted on the website of RLDCs/NLDC for viewing and validation by the Users. These schedules are open to all regional entities and other regional open access customers entities for any checking/verification, for a period of 5 days. In case any mistake/omission is detected, the entities report the same for reconciliation and appropriate rectification by the concerned RLDC. The reconciled scheduled (taking into account all before-the-fact changes in despatch schedule of generating stations and drawal schedule of the States) is termed as the Implemented Schedule and it becomes the datum for commercial accounting[2].

Q. Energy Settlement

Energy scheduled is considered deemed delivered. The scheduled energy is settled bilaterally while the deviation of actual interchange from schedule is settled with the regional pool at a frequency linked deviation rate. Thus, all before-the-fact revisions in schedule become datum for Energy Account Settlement. [1, 2]. Capacity Charges payable to the Station are based on the Declared Capacity while the energy charges payable to the Station depends on the cumulative energy scheduled by the procurers. Liability of the capacity charges is shared between the procurers in proportion of the weighted average of their entitlements in the declared capacity while the energy charge liability is shared in proportion to the energy requisitioned. Deviations, if any, from net interchange schedule are priced through the Deviation Settlement mechanism as specified by the Central Commission from time to time.

TABLE 7. TYPICAL SETTLEMENT THROUGH WEEKLY WR-POOL ACCOUNTS

Pool Account	Rs. Crore
Deviation	100
RRAS	6
Reactive Energy	2
Congestion Charge	1.5

TABLE 8. ALL INDIA RRAS ACCOUNT FOR APRIL-TO SEPTEMBER-2016

A	Regulation up		Average per unit
1	Energy scheduled	1253 MU	
2	Fixed charges paid from pool	Rs. 153 Crore	Rs. 1.22
3	Variable charges paid from pool	Rs. 316 Crore	Rs. 2.52
4	Mark up	Rs. 62 Crore	Rs. 0.50
5	Total	Rs. 531 Crore	Rs. 4.24
B	**Regulation down**		
6	Energy scheduled	153 MU	
7	Variable charges retained by RRAS provider	Rs. 7.6 Crore	Rs. 0.49
8	Variable charges refunded to pool	Rs. 22.8 Crore	Rs. 1.49

R. IT Logistics for Scheduling

Interchange scheduling involves voluminous data exchange between scheduling coordinators of SLDCs/RLDCs and multiple Sellers, Buyers, Traders and other market players. Transacting agencies refer to the schedules for billing and energy settlement. To facilitate the same a web-based energy scheduling software has been developed in collaboration with an external agency vendor. Username and password have been issued to the Users for secured interface and data exchange. Customized reports are available for viewing and for preparation of post facto energy accounts. The scheduling application also generates injection and drawal schedule for SCADA displays and RLDC website. Adequate measures are also taken to ensure cyber security. The software application requires continuous support from the IT engineers to meet the evolving regulations and procedures.

S. Data Resolution

Availability declaration by ISGS is accepted with a resolution of one (1) MW and one (1) MWh while all entitlements, requisitions and schedules are rounded off to the nearest two decimal at each control area boundary for each of the transaction, to have a resolution of 0.01 MW and 0.01 MWh [7].

T. Human Resource deployed

In every RLDC there are at least one full time equivalent as scheduling coordinators for coordination of scheduling in real-time and one for offline. There is a need for capacity building of the human resources deployed.

IV. Scope For Further Study

The interchange scheduling mechanism at the interstate level has been operating in a dispute-free manner for the last fifteen years. It has facilitated building and operation of a vibrant electricity market in India. Similar model needs to be implemented at the intrastate level urgently for optimization of the national resources and achieving economy and efficiency in the power system [22].

The synchronous interconnection of the five regional grids; phenomenal increase in the number of regional entities; complex pattern of share allocations in the Central Sector Generating Stations; manifold increase in the number of STOA transactions; and growing penetration of Renewable Energy Sources in the grid has made interchange scheduling coordination a very challenging activity. Few of emerging focus areas for future are listed below:

- Criteria for demarcation of Control Area jurisdiction
- Improving accuracy of demand and RES forecasting
- Scheduling of energy limited generation resources- and co-optimization
- Security constrained economic despatch
- Scheduling of Shunt/Series Reactive compensation devices for voltage regulation
- Scheduling of power order on HVDC links
- Implementation of gate closure for schedule revisions
- Scheduling, dispatch and settlement period for fast market
- Development of ancillary market
- Integration of scheduling software of all RLDCs
- Integration of software applications used for STOA, scheduling and metering
- Verification of committed capacity
- Faster reconciliation of schedules
- National Pool Accounts

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VI. Disclaimer

The views expressed in the paper are that of the authors' and they may or may not represent the views of the POSOCO management.

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