# Potential Applications of Short-Term Solar, Wind Generation Forecasts and Dynamic Line Rating in Indian Power System

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***Abstract*—The Indian Government has set forth an ambitious plan of setting up 175 GW of renewable capacity by 2022, which consists of 100 GW solar power and 60 GW wind power. In order to accomplish this, new challenges posed to the electric power system by current generating units, viz. variability and unpredictability must be dealt with. Initially, a brief description of the different regulations and practices pertaining to forecasting, scheduling, reserves, etc. in Indian power system is provided. Possible applications of solar-wind forecasting and dynamic line rating in Indian power system are discussed. Finally, a short summary of the suggestions made in this paper regarding the future applications of generation forecasting and dynamic line rating is presented**

***Keywords- Variable renewable energy sources, Generation forecast applications, Grid integration, Power trading, Ancillary service, Scheduling, Congestion management, Ramp management, Distributed variable renewable energy sources, virtual power plant .***

## I. INTRODUCTION

Global and national energy policies are undergoing a paradigm shift from fossil sources to more sustainable sources of energy, for addressing the issues of climate change and energy security. In its Intentional Nationally Determined Contribution, India has declared a significant scaling up of its renewable energy capacity to 175 GW by 2022. In order to accomplish this, new challenges posed to the electric power system by Variable Renewable Energy (VRE) plants, such as solar Photovoltaic (PV) and wind turbine, in the form of variability and unpredictability must, be dealt with. This requires the use of accurate VRE generation forecast, of suitable temporal and spatial resolution, and its proper utilization in the relevant activities of power system. Generation forecasts find application in Generation Scheduling and Power Trading [1], [2], Reserve Dimensioning, Ramp Management and Flexibility[3],[4],[5], Congestion Management [6],[7],[8], Active Distribution Network Management[9],[10],[11],[12] and Virtual Power Plant (VPP) Operation [13],[14], [15],[16],[17]. Usage of Dynamic Line Rating (DLR) [18],[19],[20] as opposed to the Static Line Rating (SLR), allows the system operator to make use of the available transmission capacity efficiently and prevent occurrences of congestion. This paper discusses possible utility and application of Solar/ Wind Generation Forecasting information and Dynamic Line Rating (DLR) in Indian Power System Operation, for secure and efficient operation of both the Transmission and Distribution System.

The rest of the paper is divided as follows. Section II describes the current utilization of VRE generation forecast by the different entities in Indian Power System, relevant regulations and practices. In Section III, specific applications of VRE generation forecasts and DLR are suggested for immediate future (low VRE penetration), medium term future (medium VRE penetration) and long-term future (high VRE penetration) scenarios in the Indian power system. Finally, section IV summarizes the suggestions made with regard to the potential future utilization of generation forecast and DLR.

## II. CURRENT STATUS OF VRE FORECAST IN INDIAN POWER SYSTEM

The Ministry of New and Renewable Energy (MNRE) had already come up with a proposal for setting up 25 Ultra Mega Solar Power Projects (UMPP) throughout India [21], and this has been further revised by increasing the capacity targets [22]. According to Central Electricity Regulatory Commission framework and Indian Electricity Grid Code [23], [24], all VRE units connected to the inter-state network must provide day ahead forecasts, by themselves, through principal or through lead generator, of their generation schedule to the Regional Load Dispatch Centre (RLDC). Individual VRE units or UMPPs have to provide their power feed-in forecasts to RLDC. Up to 16 intra-day revisions are allowed for updating the schedule, in order to benefit from forecasts of better accuracy. VRE units can also utilize the generation forecast made by Renewable Energy Management Centre for providing their schedules. In either case, any deviation from the forecasted schedule will be settled by means of the CERC Deviation Settlement Mechanism [25].

The concept of REMC has been introduced to provide system operators with the forecasted VRE generation of its control area [26]. The primary motivation for REMC generation forecast is grid security. Residual load calculated with this forecast, can be used for scheduling balancing resources like conventional generating units. CERC has, in its regulation on Ancillary Services, mandated that all inter-state generators whose tariff is determined by it, must provide Reserves Regulation Ancillary Services (RRAS) to the nodal agency [27]. Fifth Amendment to the IEGC states that RLDCs cannot schedule a generating unit beyond an ex-bus generation of 100% of installed capacity, to ensure availability of margin for governor action as primary response [28]. Fourth Amendment to the Indian Electricity Grid Code (IEGC) stipulates that the technical minimum for operation of a Central Generating Station (CGS) or an Inter-State Generating Station (ISGS) is 55% of its installed capacity. The concerned RLDC can direct the CGS or ISGS to operate at or above the technical minimum, on account of grid security [29].

The Forum Of Regulators (FOR) have put forward model regulation on Forecasting, Scheduling and Imbalance Handling for VRE units at the State level [30], which is in-line with the CERC framework on forecasting and scheduling. It further introduces the concept of Qualified Coordinating Agency (QCA). QCA can co-ordinate between State Load Dispatch Centre (SLDC) and individual VRE units in matters of forecasting, scheduling and is also responsible for de-pooling its aggregate energy deviation and charges to all the VRE units under it. Draft regulation on Forecasting, Scheduling and Deviation Settlement by Gujarat Electricity Regulatory Commission (GERC) has additionally laid down maximum daily revisions of 16 and 8 for Wind and Solar respectively [31]. Furthermore, it has also talked about reducing the tolerance band of deviation for wind and solar generators, on a yearly basis. Madhya Pradesh Electricity Regulation (MPERC) in its draft regulation [32] has remarked that if scheduling interval is changed from 15 minutes to 5 minutes duration, the forecast time intervals must also be modified accordingly. Karnataka Electricity Regulatory Commission (KERC) and Tamil Nadu Electricity Regulatory Commission (TNERC) have brought out actual and draft regulations [33], [34], respectively, on the same topic. Jharkhand State Electricity Regulatory Commission (JSERC) has also introduced regulations on forecasting, scheduling and QCAs [35].

Solar and Wind policy adopted by different states in India show that there will be a significant increase in the number of large and small scale VRE units connected to the state transmission and the distribution grid [36],[37],[38]. Currently, the inter-state Available Transfer Capacity (ATC) and Total Transfer Capacity (TTC) are notified three months in advance and calculated on a monthly basis [39],[40],[41].

## III. DISCUSSION

### *A. VRE Units connected to the Inter-State Transmission Lines.*

In the immediate future, VRE units connected to the inter-state grid can participate in day ahead and intra-day power exchange by using generation forecasts of different forecast horizons. Generation forecasts sent by VRE units to their respective consumers or beneficiaries and can be used by them for planning their consumption and determining their further power requirement. VRE units connected to the inter-state transmission grid through one or multiple pooling sub-stations can aggregate themselves under principal generator, lead generator or UMPPs for scheduling and accounting purpose. The smoothing effect of aggregation can lead to better and firm schedule.

In the medium-term future, inter-state VRE units can provide primary Frequency Containment Reserve (FCR), Inertial Response (IR) reserve [42]. Since the generation from VRE sources are volatile, VRE units can utilize generation forecasts to inform the REMC (RL)-RLDC about its availability in providing these ancillary services. VRE units can utilize their active generation forecast and converter ratings to forecast their reactive power potential on a day-ahead and intra-day basis to REMC (RL)-RLDC.

In the long-term future, due to the high level of VRE power output in the power system, VRE units can also provide secondary reserve services to RLDC. Generation forecasts are required here as well, so that VRE units can send reserve availability information to the RLDC. However, in order to implement this, reserve dimensioning and procurement has to be performed on a day-ahead basis at least, as the forecast accuracy decreases with increasing time horizon.

### *B. Regional Load Dispatch Centre and Renewable Energy Management Centre (RL)*

In the immediate future, aggregate generation forecasts of Inter-State VRE units by REMC Regional Level (RL) and State drawal/ injection schedules provided by SLDCs can be used to calculate the residual load or Net load on a time series basis. RLDC can compare generation and availability schedules of Inter-State Conventional Generating Stations with the residual load, to ascertain that enough generation is online or on reserve for balancing purpose, on a day-ahead and intra-day basis. Secondary frequency reserve (also AGC) needs to be enabled and procured by RLDC. REMC (RL)-RLDC can identify ramp events from day ahead and intra-day residual load forecasts and quantify them by using flexibility metrics such as ramp magnitude, ramp rate and ramp duration. These flexibility metrics can further be used to check adequacy of secondary and tertiary reserves (Reserves Regulation Ancillary Services) with sufficient ramping capability. Charges for UI in the ABT scheme of tariff can be linked to cost of ancillary reserves.

In the medium term future, REMC (RL)-RLDC can utilize nodal or park level generation forecasts of inter-state VRE units, State Network flow models with forecasted schedule and Inter-State Conventional Generating Station Schedules in a Network power flow model to determine transmission capacity of inter-state tie lines and forecast possible congestion situations, on both day-ahead and intra-day basis. Transmission constraints can be included by using Generalized Generation Distribution Factors (GGDFs), which relates the power flow over a particular line to the power in-feed from a generator [43]. This information can be utilized by users of inter-state transmission capacity for planning generation and consumption. Redispatch can be performed by RLDC in co-ordination with the respective SLDCs as a measure to relieve congestion, based on close to real time generation forecast and DLR. Inter-State VRE units can be used for providing primary response to frequency deviation. REMC (RL)-RLDC can analyze generation forecasts to determine which Inter-State VRE units are eligible for participating in the primary frequency reserve for each time interval in the forecast horizon. Reactive power potential forecast of VRE plants can be performed by using the same active power generation forecast and the inverter capacity rating. REMC (RL)-RLDC can send reactive power set-point signals to the VRE units for voltage regulation in the Inter-State transmission network.

In the long-term future, RLDC can utilize the uncertainty information of Inter-State VRE unit generation forecast and State drawl-injection schedule to perform probabilistic dimensioning and robust or stochastic procurement of reserves on a day-ahead basis. REMC (RL)-RLDC can procure secondary reserves also from VRE plants, by utilizing their generation forecast error distributions. DLR can be used in the congestion formulation instead of Static line rating, on a day-ahead basis too, as described in [44].

### C. VRE Units connected to the Intra-State Transmission Lines

In the immediate future, VRE units can use generation forecasts for scheduling their power output with the REMC (SL)-SLDC, DISCOMs, Power market and Consumers on a day ahead basis. Intra-day generation forecasts can be used to update the schedule. This becomes important under ABT, where imbalances/deviations are settled based on frequency linked UI charges.

In the medium term future, VRE units can provide primary frequency control ancillary service to REMC (SL)-SLDC by forecasting their availability on both day-ahead and intra-day basis. According to [45] Wind turbine units can provide FCR based on Constant Curtailment Strategy(CCS) or Proportional Curtailment Strategy (PCS), as shown in equations (1) and (2).

$$P_{curtailed}(t) = (1-\alpha).P_{avail}(t) \tag{1}$$

$$P_{curtailed} = P_R \tag{2}$$

$P_{curtailed}$ is the curtailed power, $P_{avail}$ maximum available power and $\alpha$ curtailment factor.

As this is a decentralized form of frequency response, participating VRE units must keep updating their availability status for future time horizons based on hour stability factor (hsf) and offer stability factor (osf), as described in [46]. Reactive Power Ancillary services can also be provided by solar PV [47] and converter based wind farms [48] to the RLDC.

In the long term future, VRE units can provide secondary reserve services to REMC (SL)-SLDC or the ancillary services market by providing generation forecasts with error or uncertainty scenarios/ distributions. To allow VRE units to participate, secondary and tertiary reserves can be procured on a day-ahead basis. VRE units can provide reactive power forecasts as well by using active power generation forecast and inverter capacity ratings. This can allow VRE units to provide reactive power ancillary services.

### D. State Load Dispatch Centre and Renewable Energy Management Centre (SL)

In the immediate future, SERCs can introduce regulations for enabling ancillary services (primary, secondary and tertiary) and Intra-State ABT in their respective states. REMC State Level (SL)-SLDC can perform aggregate VRE generation forecast of its control area at different time horizons. By utilizing aggregate load demand, VRE forecast and inter-state flows, REMC (SL)-SLDC can obtain net load demand of its control area, as shown in (3).

$$\begin{aligned} Net\ Load_t = {} & Load_t + Inter\ State\ Drawl_t \\ & - VRE\ output_t \\ & - Inter\ State\ Injection_t \end{aligned} \tag{3}$$

. This can be compared with the available dispatchable generators to ensure that sufficient balancing resource with suitable ramping capability is available at all times. Intra-day updates of residual load forecast can be used for dispatching reserves, if necessary. Empirical methods can be employed by SLDC for quantifying secondary ancillary services requirement, such as that given in [49], as shown in (4).

$$R = \sqrt{a.L_{max} + b^2} - b \tag{4}$$

$L_{max}$ is the maximum anticipated load in MW, a and b are empirical parameters.

Ramps detected from generation forecasts can be used to quantify the flexibility metrics. This can then be used to check the adequacy of ramping capabilities in reserves. Equation (5) shows a method of quantifying ramp magnitude [3], while (6) shows a method of quantifying ramp duration [50].

$$|P(t+\Delta t) - P(t)| > PR \tag{5}$$

$$PRR = \frac{|P(T+10) - P(T)|}{10} \tag{6}$$

$P(t)$ is the power output in MW, PR power ramp magnitude threshold, PRR power ramp rate.

Individual VRE units at one or more pooling stations can be aggregated under QCA. QCA can bear the responsibility of forecasting, scheduling and commercial settlement with REMC (SL)-SLDC, DISCOMs, Power market and Consumers, on behalf of the VRE units within its portfolio. REMC (SL)-SLDC can treat the QCA as a single entity with respect to forecasting, scheduling, metering and communication.

In the medium term future, VRE generation units and QCAs can also be chosen to provide primary frequency reserve ancillary services based on their availability forecasts. Past error information of VRE units can be used by REMC (SL)-SLDC to quantify the effect of VRE unit volatility on the requirement of secondary and tertiary reserve services from other sources. Each state REMC (SL)-SLDC can combine the nodal power flow model and load flow data of its own control area with the nodal model and load flow data provided by the RLDC for the inter-state tie lines. By using the combined nodal model with GGDFs and load flow data, both inter and intra state congestion situations for critical branches can be forecasted, as shown in (7) and (8) [51].

$$F_{l-k} = \sum_{g} GGDF_{l-k,g} P_g \tag{7}$$

$$\left| \sum_{g \in Conv.Unit} GGDF_{l-k,g} P(g,t) + \sum_{w \in VRE\ unit} GGDF_{l-k,w} P(w,t) \right| \leq F_{l-k} \tag{8}$$

$F_{l-k}$ is the power flow over branch l-k, $GGDF_{l-k,g}$ GGDF of generating unit g for flow over branch l-k, $P(w,t)$ wind power output, $P(g,t)$ conventional generator power outptut.

REMC (SL)-RLDC can utilize DLR and intra-day generation/ load forecasts to predict intra-day congestion situations and re-dispatch generators. Equation (9) shows DLR calculation for every 15 minute block, based on maximum allowable conductor temperature $T_C^{max}$, ambient temperature $T_A$, convective cooling $q_c$, wind speed $V_S$, wind direction $V_D$, evaporative cooling $q_e$, precipitation P, humidity H, atmospheric pressure $P_a$, solar radiation heat gain $q_s$ and corona heat gain $q_c$, as described in [52].

$$I_{max} = \sqrt{\frac{\dot{q}_r(T_C^{max}, T_A) + \dot{q}_c(T_C^{max}, T_A, V_S, V_D) + \dot{q}_e(P, H, P_a) - q_s - q_c}{R(T_C^{max})}} \tag{9}$$

Reactive power Ancillary Services can also be provided by VRE generation units and QCAs, by utilizing reactive power potential forecasts. Equation (10) gives the basic idea.

$$Q = \sqrt{S_{conv}^2 - P_{gen}^2} \tag{10}$$

Q is the VRE reactive power output, $S_{conv}$ converter maximum capacity and $P_{gen}$ active power generation.

REMC (SL) – SLDC can use past VRE Forecast Error $f^{VREFE,t}$, along with VRE variance , Load Forecast Error $f^{VREVar,t}$, Load Variance $f^{LVar,t}$, Generator Trip probability $f^{GTrip,t}$, to quantify the secondary and tertiary reserve requirement, as shown in (11) ,(12) and (13), [53].

$$f^{Total} = f^{VREVar,t} * f^{LVar,t} * f^{VREFE,t} * f^{LFE,t} * f^{GTrip,t} \tag{11}$$

$$f^{Secondary} = f^{VREVar,t} * f^{LVar,t} * f^{GOut,t} \tag{12}$$

$$f^{Tertiary} = f^{Total} - f^{Secondary} \tag{13}$$

In the long-term future, reserve dimensioning can be performed on a day-ahead basis, where day-ahead VRE generation forecast uncertainty can be used as an input for quantifying the requirement of secondary and tertiary reserves. SP and RO based scheduling algorithms can be used for procuring reserves while taking into account network security constraints. VRE generation units and QCAs can also provide secondary frequency reserve services to REMC (SL)-SLDC and power markets by providing its forecast uncertainty distribution. DLR forecasts can be incorporated into the stochastic scheduling process as transmission constraints, so as to utilize the actual available transfer capacity. According to [44], expected values of transmission capacity for different sections of line can be calculated as shown in (14), and then the minimum value is chosen as the capacity for the entire line (15).

$$E(I) = E[f(T_A, V_S, V_D)] \approx f[E(T_A), E(V_S), E(V_D)] = f(\mu_{T_A}, \mu_{V_S}, \mu_{V_D}) \tag{14}$$

$$Y = \min_{1 \leq i \leq n} I_i \tag{15}$$

$E(I)$ is the expected value of transmission capacity, $\mu_{T_A}$ expected ambient temperature, $\mu_{V_S}$ expected wind speed, i different line sections and $\mu_{V_D}$ expected wind direction.

### E. *Distribution Company Grid*

In the immediate future, Demand forecasting must be done by all DISCOMs and utilities within each state. Increase of distributed VRE sources like rooftop solar PV and Wind Turbine connected to the DISCOM grid, can impact the daily consumption profile of the DISCOM. In order to provide an accurate load forecast schedule to SLDC, DISCOMs can use day-ahead VRE generation forecast of its control area as demarcated by Intra-State ABT mechanism for calculating its residual load. In [54], the authors presented a method for calculating the residual demand based on short-term forecasts of distributed VRE generation and load, as shown in (16).

$$z_t = d_t - p_t \tag{16}$$

$z_t$ is the residual load of the DISCOM, $d_t$ power demand forecast in the DISCOM and $p_t$ VRE generation forecast at time t.

Intra-day generation forecasts can be used to update the residual load calculations. Schedules based on new residual load calculation can be sent to REMC (SL)-SLDC for intra-day revisions. QCA can act as a single entity and provide a point of communication between DISCOM control centre and distributed VRE units for forecast schedules and metered data sharing (Intra-State ABT).

In the medium-term future, reactive power capability of QCA and VRE units connected to the DISCOM grid can be utilized by the DISCOM for voltage regulation, through centralized control and decentralized regulation approaches. In [55], the authors proposed a preliminary-coarse-fine reactive power optimization method, which utilized distributed VRE forecast for voltage regulation in the distribution grid, by maintaining reactive power output from VRE inverter and switching capacitor banks. Active Power generation forecast and inverter capacity rating can be used by DISCOM to estimate the reactive power service potential of QCAs and VRE units within its area.

In the long-term future, DISCOMs can become active Distribution System Operators (DSO) by actively scheduling VRE units, QCAs, Open Access Users, Captive Power Producers, Independent Power Producers, HT and LT consumers and import from the transmission grid, on a day-ahead basis, and dispatching on a real-time basis. As described in [11], [56], this can be done through an optimization formulation which minimizes the total of import cost from transmission grid, fixed costs, dispatchable generator running and start-up costs, on a day ahead basis, represented as (17).

$$\sum_{t=1}^{24} \sum_{i=1}^{N_{disp}} c_{i,t}\, P_{i,t} + SU_{i,t} + c_{imp,t} P_{imp,t} + FC \tag{17}$$

$c_{i,t}$ Operating cost of unit i, $c_{imp,t}$ cost of power import from transmission grid, $SU_{i,t}$ Start Up cost of unit i, $FC$ Fixed Costs incurred.

In the intra-day dispatch stage, the optimization problem can be formulated as the minimization of total cost of up and down balancing actions required (18).

$$Min \sum_{t=1}^{24} \sum_{i=1}^{n_g} \Delta P_{imp,t}^{up} + \Delta P_{imp,t}^{dn} + \Delta P_{disp,i,t}^{up} + \Delta P_{disp,i,t}^{dn} + \Delta P_{flexLoad,i,t}^{up} + \Delta P_{flexLoad,i,t}^{dn} + \Delta P_{VRE,i,t}^{up} + \Delta P_{VRE,i,t}^{dn} + \Delta P_{QCA,i,t}^{up} + \Delta P_{QCA,i,t}^{dn} \tag{18}$$

$\Delta P_{imp,t}^{up}$ $\Delta P_{imp,t}^{dn}$ up and down regulation in power import from main grid,, $\Delta P_{disp,i,t}^{up}$ $\Delta P_{disp,i,t}^{dn}$up and down regulation in power from dispatchable units, $\Delta P_{flexLoad,i,t}^{up}$ $\Delta P_{flexLoad,i,t}^{dn}$ up and down regulation in power consumption by flexible load, $\Delta P_{VRE,i,t}^{up}$ $\Delta P_{VRE,i,t}^{dn}$ up and down regulation in VRE power output,, $\Delta P_{QCA,i,t}^{up}$ $\Delta P_{QCA,i,t}^{dn}$ up and down regulation in QCA power output.

DISCOMs can procure balancing resource from ancillary service market or contracts, dispatchable generation units, flexible loads, VRE units and QCAs. By including voltage band limits of all buses in the optimization constraints, active and reactive power dispatch set-points can be sent to the participating entities.

### *F. Qualified Co-ordinating Agency*

In the immediate future, QCAs can take up the role of VPP and can be setup in both transmission and distribution grid. At the transmission grid level, it can be used for aggregating one or more VRE generation pooling stations by providing a single forecasted schedule for entities under it, to REMC (SL)-SLDC. QCA can be in charge of pooling/ de-pooling schedules/deviations of the VRE units in its portfolio. In order to do this, QCA must estimate generation forecasts of the VRE units under it. QCAs can use day-ahead generation forecasts for providing schedules to REMC (SL)-SLDC, Power Market, Other consumers. Intra-day forecasts can be used to revise the schedule so as to minimize deviation from real-time condition. QCA can also be introduced in the distribution sector as distribution entities, which can aggregate small wind turbines and roof-top solar PV based VRE units connected to one or more distribution pooling stations. In this case, the QCA can provide day-ahead schedule and intra-day revision forecasts for the total connected VRE generation units at the pooling station or stations under it, to the DISCOM.

In the medium-term future, QCAs can make a portfolio of diverse entities like VRE units, Large Industrial flexible loads, Storage units, Conventional generation units, bio-mass plants, hydro/pumped hydro stations, which can be physically located at different pooling stations of the Transmission grid. QCA can use VRE generation forecast as an input parameter in formulating generation schedules for REMC (SL)-SLDC, Consumers or for maximizing profit at the power market QCA operational practice can comprise of two parts – day ahead scheduling and intra-day dispatch, as described in [16]. The day-ahead objective is to minimize the operational cost of the QCA, by taking into consideration different VRE scenarios s with probability $p_s$ (18).

$$\min \sum_{s=1}^{N_s} p_s \left( \sum_{t=1}^{T} \left( \sum_{i=1}^{N_{disp}} c_{disp,i} P_{disp,i,t,s} + \sum_{j=1}^{N_{sto}} C_{sto,j,t,s} - P_{sell,DA,t,s} c_{sell,DA} \right) \right) \quad (19)$$

$N_s$ number of scenarios, $p_s$ probability of scenario s, $N_{disp}$ number of dispatchable units, $c_{disp,i}$ operating cost of dispatchable unit i, $P_{disp,i,t,s}$ power output of dispatchable unit i at time t in scenario s, $N_{sto}$ number of storage units, $C_{sto,j,t,s}$ total operating cost of storage unit j at time t in scnario s, $P_{sell,DA,t,s}$ power sold to grid in Day Ahead (DA) market at time s in scenario s, $c_{sell,DA}$ price of power sold to grid in DA market.

In intra-day dispatch, the objective is to deliver the day ahead settled power exchanges by adjusting dispatchable sources or paying imbalance penalties if necessary. So, the objective function is the minimization of dispatchable unit cost, storage cost and imbalance cost (19).

$$\min \sum_{t=1}^{T} \left( \sum_{i=1}^{N_{disp}} c_{disp,i} P_{disp,i,t} + \sum_{j=1}^{N_{sto}} C_{sto,j,t} + c_{imb,t} P_{imb,t} \right) \quad (20)$$

$c_{imb,t}$ Cost of imbalance power, $P_{imb,t}$ imbalance power exchange with the grid.

As a major fraction of generating capacity in any QCA is based on VRE units, it can utilize VRE generation forecast to provide its availability schedule for primary frequency response service to REMC (SL)-SLDC. In distribution grid, QCA can expand to include HT consumers, Captive power producers and pumped/battery storage units. QCAs can provide reactive power ancillary service to REMC (SL)-SLDC or DISCOM, by utilizing real–time and forecasted availability information.

In the long-term future, QCAs can provide secondary and tertiary reserve services to the grid. They can plan different quantum for energy trading and ancillary services. Depending on the controllability of the units under the QCA's control, it can use scheduling algorithms for maximizing its profit, following the load, etc., by utilizing generation forecasts for VRE units and availability schedules for dispatchable units.

## IV. CONCLUSION

Short term VRE generation forecasting is extremely important for smooth operation of grid and management of a large share of power from VRE. Currently, control area level aggregated generation forecast has been initiated for residual load calculation by Load Dispatch Centers (LDCs) on a day ahead and intra-day basis, in the Indian power system. On the other hand, a separate kind of short term generation forecasting at the level of individual plants/ pooling transformer stations has also been initiated in several Indian States for scheduling and accounting purposes. This paper highlights potential additional future applications of VRE generation forecasting and DLR in Indian power system. These include generation forecast by VRE units and QCAs for participating in power exchange and ancillary services market, generation forecast by LDCs for residual load calculation, ramp management, reserve dimensioning and ancillary service procurement. It also suggests the use of DLR by LDCs for congestion management, and generation forecast by DISCOMs for smooth operation and scheduling of the distribution grid. As described in detail in the paper, the nature of generation forecast itself can change with the change in VRE penetration level, for serving various purposes. Probabilistic generation forecasts and DLR can find application at higher levels of VRE penetration into the electricity grid, where it is necessary to take into account the uncertainty of prediction in the decision making processes. DLR can also be forecasted on a day-ahead basis in order to incorporate predicted dynamic ratings in relevant decision making processes.

Though at the present moment there are only two principal types of forecast applications in India, in the future with the increase in share of electrical power from VRE sources, more kinds of usages of generation forecasting is inevitable in India.

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