# A Simple Functional Relationship of Error distribution of Day-Ahead Power Generation Forecast and the Variability of Power Generation

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***Abstract*— Forecasting of power generation is an essential requirement for high penetration of variable renewable energy in an existing grid system to reduce the uncertainty of renewable generation. This paper focuses on the statistical behavior of error in solar and wind power forecasting considering Indian regulations and analyze the minimum value of variance of the forecast error distribution. The functional relationship considers the variability of the power generation and the correlation coefficient between actual and forecast power generation.**

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## I. Introduction

Wind and solar energy are two major components in renewable energy generation in India [1-4]. But the unscheduled fluctuations of wind and solar generation produce ramping events and hence the integration of significant wind and solar energy into the existing supply system is a challenge for large scale renewable energy penetration [5-11]. The wind and solar create a balancing issue in managing the grid due to variability and intermittency. Hence, to accommodate the variability in demand-supply system, the day-ahead and short-term renewable energy forecasting is needed to effectively integrate renewable energy to the grid and the forecasting and scheduling of wind and solar energy generation has become an important area of research in Indian context [12-13]. Since the system operators in India have to do curtailment of variable renewable energy due to intermittency and variability of the wind and solar power generation, the forecasting takes an important role in creating a sustainable solution for maximum utilization of renewable energy.

The concept of forecasting and scheduling (F&S) of renewable energy generators and the commercial settlement was introduced in Indian context by CERC through Indian Electricity Grid Code (IEGC), 2010 [14] and the Renewable Regulatory Fund mechanism [15]. To develop an implementable framework, CERC issued 2nd amendment to regulate for Deviation settlement mechanism and other related matters [16]. After CERC regulation, Forum of Regulators (FOR) [17] and other state regulators issued or drafted regulation related to the forecasting and scheduling of Wind and Solar power generation.

The formal strategy in F&S of wind and solar power generation is predicting the weather parameters using of NWP (Numerical Weather Prediction) models and changing the values of weather parameters into power generation using the turbine or PV models considering the CFD (Computational Fluid Dynamics) based analysis in local areas. The recent development of deep learning algorithms in ANN (Artificial Neural Network) based methodologies have created a huge scope in forecasting the power generations. Considering the uncertainty in the initial value vector in NWP and learning vectors in DNN (Deep Neural Network), a powerful perspective regarding the forecasting methodology is to regard it fundamentally as a statistical rather than deterministic solutions as the stability of the grid needs not just the production of power generation but also the uncertainty associated with it. Thus from a mathematical viewpoint, forecasting is best considered as the study of the temporal evolution of probability distributions associated with variables in the power generation.

In this paper, a simple functional relationship of variance of forecast error distribution is established considering the variability of power generation and the correlation coefficient of the actual and forecast power generation. The remaining of the paper is organized as follows: The section II describes the simple theoretical structure of the functional relationship. The results and brief analysis are discussed in Section III and the conclusion is presented in section IV.

## II. Functional Relationship of Error Distribution

The required functional relationship of the variance of the forecast error distribution can be described using simple algebraic manipulation of the forecast error and the variability of the actual power generation.

### *A. Forecast Error*

Considering the CERC and other state regulations, the forecast error at *i*-th Time Block (1 Time Block = 15 minutes) can be defined as [15, 17]

$$e_i = \frac{1}{AvC}\left(P_A(i) - P_S(i)\right) \quad (1)$$

Where $AvC$ is the available capacity of the plant under consideration; $P_A(i)$ and $P_S(i)$ are actual generation and scheduled generation respectively. The mean and the variance of the error distribution can be represented as,

$$\mu_e = \frac{1}{N}\sum_{i=1}^{N} e_i = \frac{\overline{P_A} - \overline{P_S}}{AvC} \quad (2)$$

$$\sigma_e^2 = \frac{1}{N}\sum_{i=1}^{N} e_i^2 - \mu_e^2 \quad (3)$$

*B. Variability in Power generation*

Variability of power represents the change of generation output due to unscheduled fluctuations of wind velocity or sun radiation patterns while uncertainty describes the inability to predict in advance the changes in generation output. Large unscheduled changes in wind or solar power generation are called ramp events which hamper the penetration of variable power in the existing grid [13]. The variability can be quantified as a measure of dispersion in variable renewable power generation and be easily quantified using the concept of Lorenz curve [18]. Though there are different ways to quantify variability, the simplest way to measure variability is using the normalized squared deviation about the mean of the actual generation for some time block *N* as follows,

$$\sigma_A^2 = \frac{1}{n\,Avc}\sum_{i=1}^{n}(P_A(i) - \overline{P_A})^2 \quad (4)$$

Similarly the dispersion in the schedule generation for the same time span can be represented as

$$\sigma_S^2 = \frac{1}{n\,Avc}\sum_{i=1}^{n}(P_S(i) - \overline{P_S})^2 \quad (5)$$

*C. Minimum value of Variance n Error Distribution*

Considering (3), (4) and (5), it is easy to state that,

$$\sigma_e^2 = \sigma_A^2\left[1 + \left(\frac{\sigma_S}{\sigma_A}\right)^2 - 2r\frac{\sigma_S}{\sigma_A}\right] \quad (6)$$

Hence, by simple algebraic manipulation,

$$\frac{\partial\sigma_e^2}{\partial\sigma_S} = 0 \rightarrow \sigma_S = r\sigma_A \quad (7)$$

$$\frac{\partial^2\sigma_e^2}{\partial{\sigma_S}^2} = \frac{2}{\sigma_A^2} > 0 \quad (8)$$

Equation (7) and (8) shows that the minimum value of the standard deviation of the error distribution occurs at $\sigma_S = r\sigma_A$ . Hence, using (6), the required functional relationship can be represented as an inequality,

$$\sigma_e^2 \geq (\sigma_A^2 + \delta)(1 - r^2) \quad (9)$$

Here $\delta$ can be viewed as a stochastic parameter. Equation (9) shows the minimum value of the variance of the error distribution and can be used in calculating the minimum value of the penalty due to deviation in forecast power generation and the accuracy of the forecast system.

## III. Result and Discussion

The functional inequality shows the minimum value of the variance of the error distribution. Considering the scenarios of the F&S regulations in different states in India, the value of the variance reflects the value of the penalty due to the deviation. We can consider that the variance in error distribution is directly related to the penalty due to the deviation as well as the accuracy of the forecast system. Hence this inequality plays a significant role in deciding the forecast system required for the wind or solar plant under consideration. Figure (1) shows the variation of minimum value of the standard deviation of the forecast error distribution for different value of the correlation coeficient.

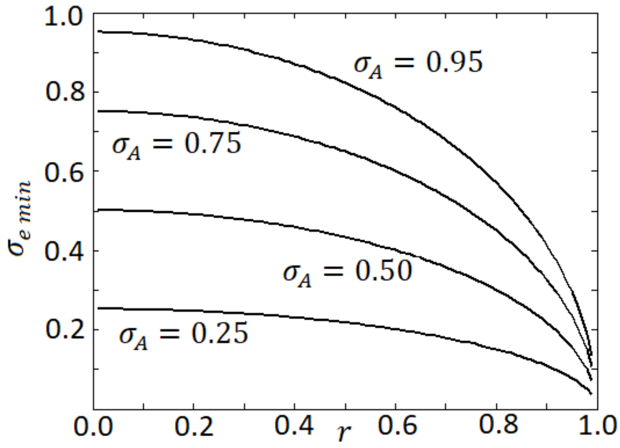


Figure 1: Charecteristics of the minimum value of standard deviation of error distribution $\sigma_{e\,min}$ and the correlation coefficient *r* for different value of standard deviation of the actual power generation, $\sigma_A$

Without loss of generality, we can consider that the forecast error distribution follows a Normal distribution with mean 0 and standard deviation $\sigma_e$ i.e. $e \sim N(0, \sigma_e)$. For a standard Normal distribution *N*(0,1), the area under the curve is 99% when the *z* values lie between -2.576 and +2.576 i.e. in standard notation,

$$Prob(-2.576 \leq z \leq 2.576) = 0.99 \quad (10)$$

Hence we can state that,

$$Prob(-2.576\sigma_e \leq e \leq 2.576\sigma_e) = 0.99 \quad (11)$$

Equation (11) shows that if the error in forecast lies between the $-2.576\sigma_e$ and $2.576\sigma_e$, the accuracy of the forecast reaches to 99%. Since there is no-penalty due to deviation if the forecast error defined by (1) lies in +/- 15% according to CERC regulation, we can consider,

$$2.576\sigma_e \leq 0.15 \quad (12)$$

Equation (12) states the maximum value of the standard deviation for 99% accuracy for CERC regulation is $\sigma_{e\,max} = 0.06$ . Considering the stochastic variation in actual power generation is very small ($\delta \rightarrow 0$), using (9),

$$r_{min} = (1 - 0.0036\sigma_A^{-2})^{0.5} \quad (13)$$

Equation (13) shows a direct relationship between the variability of the actual power generation and the minimum requirement of the correlation coefficient of actual and forecast power generation for the accuracy of 99% in case of no-penalty zone is +/- 15% according to CERC regulation. Using (13), if the variability in the actual power generation is very high, the requirement of *r* tends to 1 to maintain the same accuracy of 99%. Using (9) we can also state that how much variation in actual power generation can be accommodated in the forecast system to get the accuracy of 99% in case for CERC regulation. Considering, *r* =0.99 and $\sigma_{e\,max} = 0.06$, using (9) we can state that, $\sigma_A \leq 0.425$. Hence, for 99% accuracy in forecasting under CERC regulation the forecast system must accommodate the variability 0.425. If variability of the actual power generation is more than this value, the accuracy of the forecast will be reduced. As an example the brief analysis of a solar plant at Tamil Nadu, India is shown in Table I. It is interesting to see that the penalty due to deviation (as percentage of revenue) decreases (hence the accuracy of forecast increases) with the increment of the variability in actual power generation. It is interesting to see that the Tamil Nadu is affected by two Monsoon and the variability also changes due to the non-operatinal issues in the solar plant.

TABLE I: Shows the variability analysis and penalty due to deviation (as percentage of revenue) for a Solar Plant at Tamil Nadu, India

| Month | Varibility of Actual power generation | Penalty due to deviation ( % of revenue) | Comments |
|---|---|---|---|
| Nov-16 | 0.4834 | 0.2902 | Retreat of South-West Monsoon |
| Dec-16 | 0.4722 | 0.2415 | North-East Monsoon |
| Jan-17 | 0.4793 | 0.2803 | North-East Monsoon |
| Feb-17 | 0.4527 | 0.1084 | Dry Season |
| Mar-17 | 0.5327 | 0.3451 | 10 days of Non-operation |
| Apr-17 | 0.4371 | 0.0209 | Dry Season |
| May-17 | 0.4683 | 0.1488 | 5 Days Non-operation |
| Jun-17 | 0.4432 | 0.0668 | Dry Season |

## IV. Conclusion

This article derives a simple functional relationship between the variance of the forecast error distribution, variability of the actual power generation and the correlation coefficient of the actual and forecast power generation. The functional inequality can be used in finding the lower and upper bounds of the accuracy of the forecast system considering different state regulations for forecasting and scheduling of wind and solar power generation. The stochastic behavior of the functional relationship can accommodate the uncertainty in forecasting process and is under development. The functional relationship shows an easy understanding of the variability of power generation and the accuracy of forecast process and can be used in calculating the penalty due to deviation in forecasting variable power like wind and solar.

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## Biographical Information

**Abhik Kumar Das** holds a Dual Degree (B.Tech in Electronics & Electrical Communication Engineering & M.Tech in Automation and Computer Vision) from Indian Institute of Technology, Kharagpur, India. He has a vast experience in computational modelling of complex systems. He contributed in different verticals of analytical modelling related to renewable energy and techno-economics and published several well-cited research articles in internationally acknowledged journals and peer-reviewed conferences. He is founding member of del2infinity, an accurate Wind Energy & Solar Energy Forecasting and Scheduling Solutions Company. (e-mail: contact@del2infinity.xyz).