Short Term GA-NFIS based Hybrid Method for Prediction of Wind Speed & Power in Sustainable Power Generation

Vijay Kumar, Yash Pal, Madan Mohan Tripathi

Abstract**:** ***Additional power requirement and integration of non conventional energy sources for power generation into smart grid, forced the world power generating company to divert their attention towards power generation from renewable sources along with conventional sources. Today power demand in different sectors are increasing with continuous increasing population, so it is very challenging task for power generating company to maintain balance between supply and demand. The countries that consume more energy per capita are supposed to have better social- economical status and living standard. Currently power generation from the conventional sources faces many challenges such as environment pollution, continuous availability, storage and security; to mitigate the above problems power generation from renewable sources may be better alternative. So, many countries started power generation from renewable sources such as wind power and solar power by expanding major portion of their energy fund into development of the renewable setup for power generation. In India currently wind power contribution in renewable power sources is very high so, wind may be a better solution for power generation. Power generation from wind puts many barriers in term of intermittent nature, frequency and availability at all places with certain speed that is able to power generation from wind mills. Although above challenge cannot eliminate completely, but it can be minimize with the help of correct prediction technique / method that have accuracy up to certain level which will be acceptable for power generation. In this work GA- NFIS is used for forecasting of wind power and data is collected from Indian wind power sector mills. Results of proposed method are compared with some available soft computing methods such as NARX, SVM-NARX.***

Index Terms**:** ***Prediction, Wind power, Genetic Algorithm, Neuro- Fuzzy Inference System, Speed prediction, Absolute Percentage Error (APE).***

I. INTRODUCTION

With rapid growing population along with industrialization in the world currently power demand and its proper supply from different sources has become serious issue for the whole country of the world. To fulfill the current requirement of energy we cannot depend only on conventional method of power generation or sources due to its limited storage, pollution. So, there will be requirement of balance between demand and supply while insuring the minimum possible pollution. By increasing the contribution of renewable share in power generation above problems can be reduce up to some extent. For this purpose wind power may be one of the good alternative solutions [1]. The main problem of power generation from wind is its unpredictable nature with varying speed and it can be minimize up to certain acceptable level with suitable prediction of wind speed with good accuracy that will enhance power generation economically. Due to highly dependency of wind power on speed, very small error in speed prediction will reflect considerable error in power calculation. Keeping the above point there will be requirement of such types of technique / method that will predict speed with minimum error [2]. Now days many different methods/ techniques are available in the field of forecasting such as ARMA / ARIMA model, Persistence method, Physical, Statistical method, NWP, AI based methods. Depending on situation and requirement of time interval different methods are utilized [4] [5]. Paper is distributed into 7 section such as section 1 give the brief introduction, section 2 discuss about genetic algorithm (GA), section 3 provide basic information about Neuro-Fuzzy Inference System (NFIS), section 4 describes the forecasting procedure of suggested method by GA & NFIS, section 5 provide the knowledge of basic error parameters related to prediction, section 6 shows results, comparison with others method and last section tells the conclusion. The result comparison indicates that proposed method provide better results compare to other.

II. ARTIFICIAL INTELLIGENCE BASED METHOD (ANN)

Before the regulated electricity markets Neural network was primarily applied on load & price forecasting, but currently it is also apply in the field of wind parameters prediction like speed and power [6]. ANN has capability to save the computing time by minimizing numbers of variables during training process [7]. ANN provides better result for time series data in different time slots with respect of other conventional methods. In modeling time series data generally we use nonlinear autoregressive exogenous model (NARX), in which present exogenous based input value reflect a relationship to the previous value. NARX model can be mathematically modeled through equation 1.

$$R_m = P\,(x_{t-1}, x_{t-2}, x_{t-3\ldots}\ m_t, m_{t-1}, m_{t-2}, m_{t-3\ldots}) + E_t \qquad (1)$$

Here x_i represent variable of interest, *m* determination variable & E_t error. Basic Multilayer (3- layer) ANN is shown in figure 1 this network comprises of different layers such as inputs, hidden and corresponding to output. Modeling parameters of the network can be expressed by expression.

$$(R, t) = (R^{(1)}, t^{(1)}, R^{(2)}, t^{(2)}) \qquad (2)$$

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$R_{mn}^{(l)}$ reflect corresponding associated weight of units existing in layer l, with the corresponding units of m+1 layer, $t_m^{(l)}$ represent associated bias of unit m in m+1 layer. The ANN structure takes the previous data and current trends to predict the future data [14].

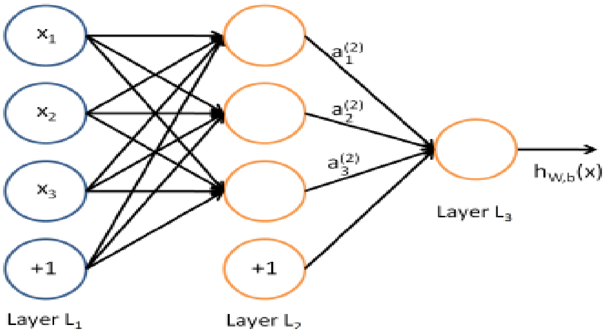

Fig.1: Multi-layer ANN

III. GENETIC ALGORITHMS (GA)

In the field of AI applications Genetic algorithm may be one of the most efficient and better computing technique/method in case of forecasting [8]. It works on principle of random searches technique with the help certain set of existing alternatives in attempt to find out best possible alternative based on the provided criterion. The different set of criteria is represents via an objective function that also known as fitness function. Working/ searching procedure for optimization condition of GA is represented in figure 2.

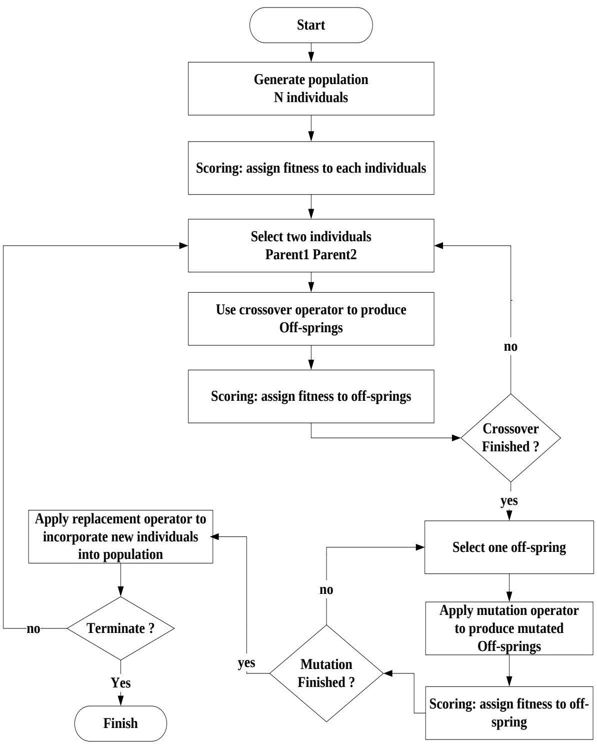

Fig.2. Working Procedure of Genetic algorithm

Suppose objective function is represented by G (n), which is to be optimized, suppose k_i , p_i is a constant and input variables respectively. Main aim of objective function is such that the value of equation represented by equation 3 will provide optimized value.

$$k\ (p_1, p_2\ldots\ldots\ldots\ldots p_9) \tag{3}$$

Where k_i (p) $\geq$ 0, for every i=1, 2, 3…n. Expression represented via k (p_1, p_2…………p_9) is variables. During processing GA sustained a population of G individuals such that Pop (k) = (p_1 (k),...,p_G (k)) for each calculation iteration there will k (generation variables) even single individual has capability to represents a good result for related objective function. In consecutive step 2 chromosomes may be taken as parent & next populations will be generating by crossover and mutation of above two chromosomes. With generation of new population, new fitness function again calculates for each set of chromosome. Out of this best fitness function and objective function are selected as parent chromosome for next calculation / generation. In this process with help of crossover operator, 2 new off springs are generated. Crossover operator generally applied on those particular members that have high probability of fitness. This process is repetitive and will repeat till required / termination criteria meet.

IV. NEURO – FUZZY INFERENCE SYSTEMS (NFIS)

NFIS provide better solution for such types of problems that is related to approximation of functions & may be regarded ANN in case of data driven process [9-11]. During nonlinear forecasting it takes the previous data to predict future data via including the self-learning ANN characteristics as well as NFIS function approximation procedure [12-13]. At the stage of final output estimation weighted data of each participant variables are consider. Figure 3 shows the basic structure of NFIS.

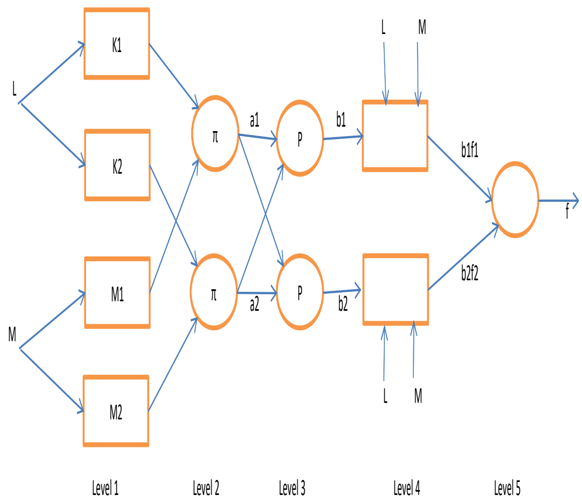

Fig.3. Basic structure of NFIS

NFIS network structure includes 5 corresponding internal layers in which each separate layer composed many numbers of nodes which is represented via node function. Functions as well as description details of each layers are described as below.

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Layer 1: In this layer every node *n* is belong to other node via function that is given by equation 4.

$$P_n^1 = \mu M_n(R) \quad (4)$$

Where R is input related to node *n*, M_n label corresponding node n. Membership functions related to input variables are represented by equation 5.

$$\mu m_j(R) = \frac{1}{1 + \left| \frac{R - r_j}{m_j} \right|^{2b_j}} \quad (5)$$

here R is input and $\{k_n, b_n, r_n\}$ is corresponding related parameter of node.

Layer 2: Individual node is fixed type node, it is responsible for rule based estimation of firing strength a_n. Output related to each node may be product of each input signals that is denoted by equation. (6).

$$P_n^2 = a_j = \mu M_n(R) = \mu M_n(m) \qquad n = 1, 2, 3 \quad (6)$$

Layer 3: Like layer 2, every node is fixed. For the calculation of total firing strengths of combined nodes each n^{th} node check the ratio of n^{th} node . Final output strength some times called as normalized strengths that can be represented by equation (7).

$$p_n^3 = \overline{b_n} = \frac{a_n}{a_1 + a_2}, \text{ Where } n = 1, 2, 3, \ldots \quad (7)$$

V. ERROR PARAMETERS ESTIMATION

Accuracy of predicted technique / model is examined by estimation of different error parameters related to forecasting such as RSME, Mean bias error and Root Mean Square Error. Estimated parameters can be represented through equation 8, 9 and 10.

(i) RSME can calculated as

$$RSME = \sqrt{\frac{1}{K} \sum_{i=1}^{K} (P_{ki} - P_{ci})^2} \quad (8)$$

(ii) MBE can calculate

$$MBE = \frac{1}{K} \sum_{i=1}^{K} (P_{ki} - P_{ci}) \quad (9)$$

(iii) MAE can calculate as

$$MAE = \frac{1}{B} \sum_{i=1}^{n} \left| (P_{mi} - P_{ci}) \right| \quad (10)$$

Here $P_{ki,}$ P_{ci} is the actual power & forecasted power related to i^{th}, n represent the number of times that observation taken.

VI. PROPOSED TECHNIQUE

Currently proposed technique utilizes a hybrid method based on GA, and NFIS. First stage available input wind data's are normalized via in data processing, after that this normalized data is used for training and validation of proposed GA-NFIS model. Predicted values of prepared data sets for particular interval depending on requirement are forecasted by proposed GA- NFIS method. During forecasting process genetic algorithm (GA) is used to enhance final performance associated NFIS structure. After that final predicted wind data is used for the error estimation that will reflect the correctness of proposed method. Proposed working model of GA-NFIS is represented by figure 4.

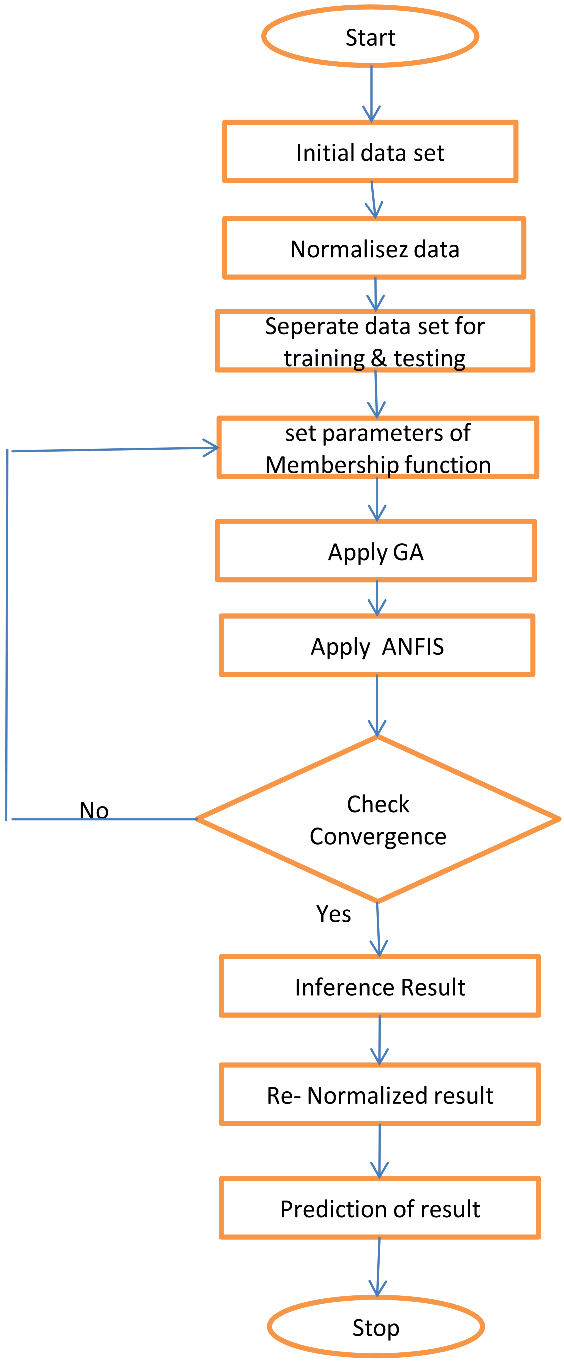

Fig.4. Proposed GA-NFIS model

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VII. FORECASTED RESULTS

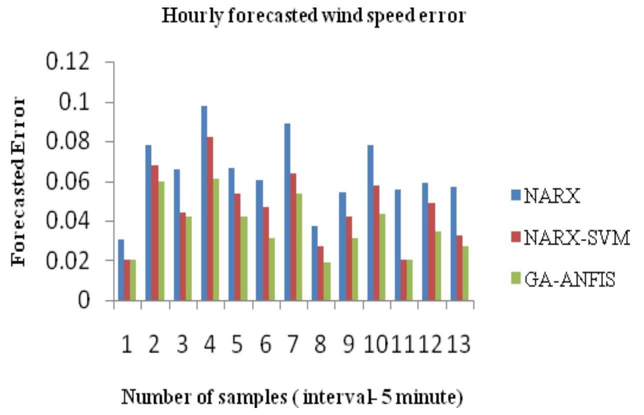

Fig. (5a) Forecasted error in speed

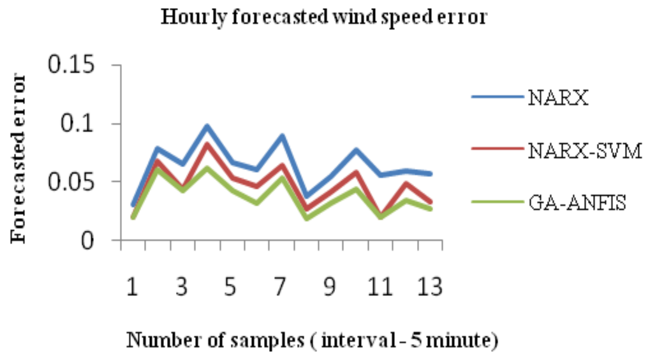

Fig. (5b) Hourly Forecasted error in speed

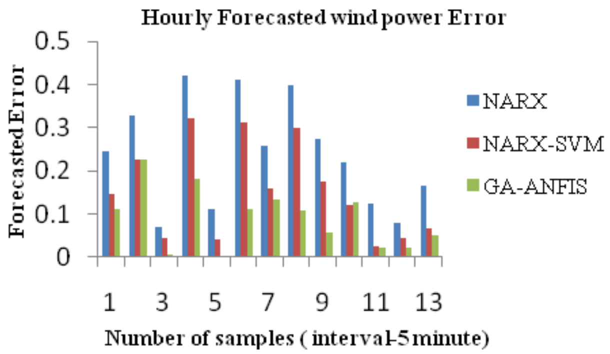

Fig. (6a) Hourly Forecasted error in power

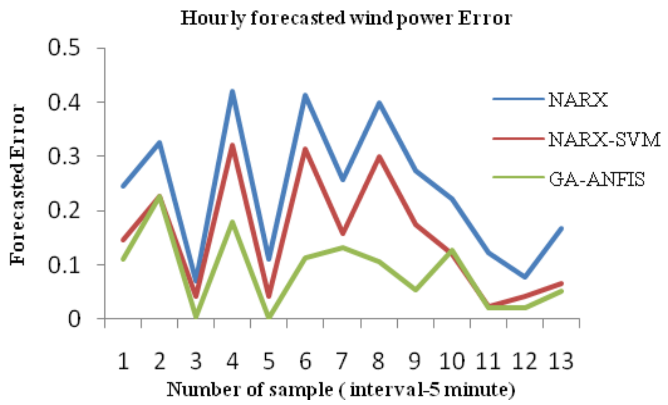

Fig. (6b) Forecasted error in power.

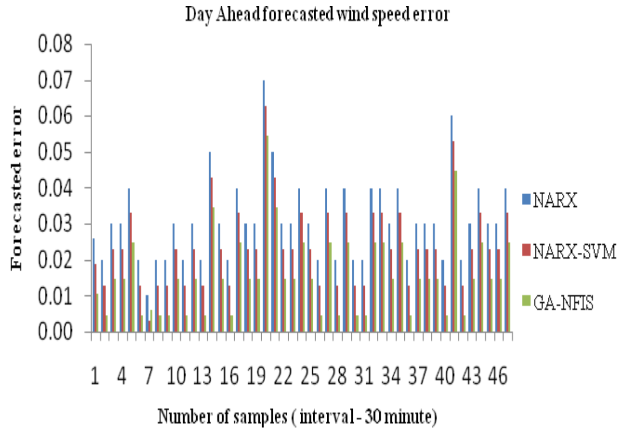

Fig. 7 Forecasted error in speed

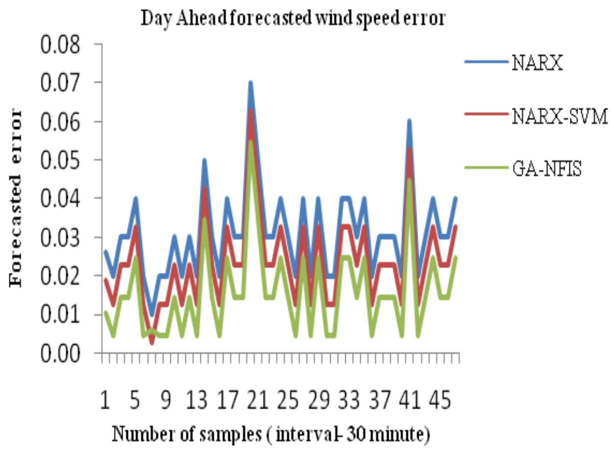

Fig. 8 Error prediction in speed

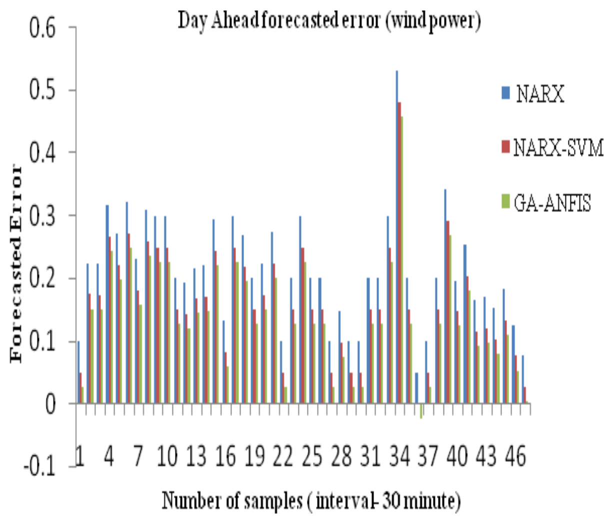

Fig. 9 Error prediction in power

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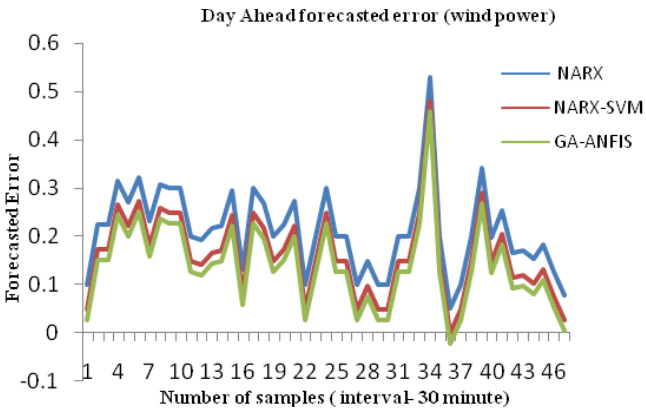

Fig. 10 Day Ahead error in wind power prediction

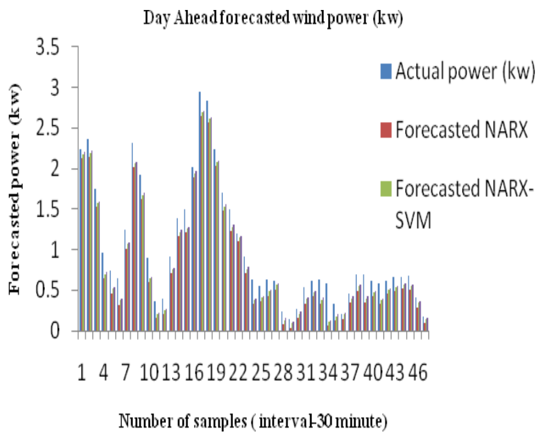

Fig. 11 Day Ahead predicted wind power

Table 1 & 2 shows the corresponding MAPE for wind speed is & power for NARX, NARX-SVM & GA-NFIS.

Table 1. PERCENTAGE MAPE FOR SPEED

Prediction Technique	Hourly MAPE	Day Ahead	Weekly MAPE	Monthly MAPE
NARX	7.28	8.57	9.24	9.55
NARX-SVM	5.79	6.22	7.33	8.18
GA-ANFIS	4.17	5.46	5.68	6.19

Table 2 PERCENTAGE MAPE FOR POWER

Prediction Technique	Hourly MAPE	Day Ahead	Weekly MAPE	Monthly MAPE
NARX	8.48	9.69	9.78	9.88
NARX-SVM	6.69	7.22	7.37	7.79
GA-ANFIS	4.79	5.85	6.34	6.86

VIII. CONCLUSION

With help of accurate and reliable prediction method that will provide minimum error between actual and predictedvalue we can increase the reliability and sustainability of wind power generation and its integration into smart grid that will help in power deficiency mitigation. The current proposed GA-NFIS based hybrid method is apply on the wind data obtained from Indian wind energy form for short term prediction and analysis of results shows good improvement in term of MAPE parameter as compare to NARX, NARX-SVM and few other methods. Comparative analysis of 3 different methods i.e NARX, NARX-SVM and GA-NFIS are shown in table 1 & 2. From the table 1, table 2 and figure 5 to 11 it is clear that proposed method i.e GA-NFIS give better result in term of error parameter MAPE. For hourly, day ahead, weekly and monthly wind speed prediction GA-NFIS provide MAPE 4.16, 5.46, 5.68 and 6.19 respectively, while for wind power prediction it is 4.79, 5.85, 6.34 and 6.86 respectively which better than other two methods for same prediction time interval.

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