

PIONEERING OF A PREDICTION METHOD FOR WIND SPEED AND VALIDATION FOR LOCAL SITE RECORDS

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ABSTRACT

The economic benefit of having wind speed predictability is obvious. To ensure security of supply, a power system operator must plan the scheduling of power units to meet the load demand at minimum cost. Demand must be well predicted to schedule and plan as effectively as possible. Also variable speed control schemes may depend on wind speed and its prediction. A new method for wind speed forecasting is presented and verified for data of a local site at Chandona, Gazipur., This algorithm makes use of memorized wind speed to predict the next step wind speed. It is shown that as long as the wind speed variation is not extremely brisk, the proposed predicting algorithm is able to predict wind speed with a fairly good precision. There exist a time lag between predicted wind speed curves and actual wind speed curves. The predicting method simulates the records at different orders. But using higher order predictor for the proposed algorithm can achieve fairly good prediction than lower order predictors. As we move towards the higher order predictors, heavy computations occur and more memory coefficients become involve in computations along with increased number of memorized wind speed data. The proposed predicting scheme does not assume the precise knowledge of the wind model.

Keywords: Wind Power, Prediction Algorithm, Memory Coefficients.

1. INTRODUCTION

Wind energy represents one of the valuable resources that are non-polluting and free. They're many islands along the Bay of Bengal which are prospective areas for wind power generation. This wind blows over Bangladesh from March to September with a monthly average speed 3 m/s to 6 m/s. [2]. During the months starting from late October to February wind speed remains either calm or too low. The peak wind speeds occurs during the months of June, July. The monthly average wind speeds during these periods are about 6 m/s [2]. This speed is quite enough to operate a 55 kW wind generator in the coastal areas and islands especially at Kuakata, St.Martin, Patenga, Char fashion etc. Park of wind turbines in these areas, can be incorporated in electricity grid on a substantial basis and could add reliability and consistency to the electricity generated by the Kaptai Hydro-electric power Station from March to September, during which load shedding becomes critical than winter season. So the deficit power could be compensated with the help of wind power plants along the coastal zone. Besides these, there are a lot of hilly and remote areas with a great open space inland where the wind speed remains 2 m/s to 5 m/s in Bangladesh.[2] The recent development of wind rotor aerodynamics makes it feasible to extract energy from wind speed as low as 2.5 m/s.

The energy available in the wind is in the form of

kinetic energy. Total available power,

$$P_T = \frac{1}{2} \rho A v^3$$

where, v = measured wind speed (m/s)

ρ =density of air (1.19-1.22 kg/m³)

So, wind power increases with the velocity cubical relation. The more the velocity the more will be the power. For a particular site the velocity is higher at a higher altitude. Density of air decreases with increasing altitude which causes decrease in power generation. But it has a lesser effect (as linear relation) on power generation. In fact, the wind machine cannot intercept all the energy theoretically available in wind because limitations are involved by other factors. In practice, the actual available energy will be obtained by multiplying a power coefficient (C_p) taking into account the efficiency of the wind machine. The integration of wind energy into a large scale power system is an attractive proposition in terms of diversity of supply and minimal atmospheric emissions.

The major challenge in design and control of wind power generation stems from the fact that in contrast to conventional generation, where input energy from the prime mover can be scheduled and regulated, wind energy is not a controllable resource due to its intermittent and stochastic nature. So, prediction of wind speed have an economic benefit for wind speed power generation. To ensure security of supply, a power

system operator must plan the scheduling of power units to meet the load demand at minimum cost. Inevitability

2. INEVITABILITY FOR A NEW METHOD

Precise forecast of wind behavior is generally unavailable. However, a number of methods can be used for wind speed prediction with a reasonable accuracy. Typical methods for wind power prediction include Off-site Observations and Numerical Weather Prediction Method, Challenge Method, Regime-switching Space-time (RST) Method, Time series method, Neural Network method, Artificial Neural Network Method [3-6]. The most popular method for wind speed forecasting appears to be the time series method as explored in [6]. It should be mentioned that most existing prediction methods for wind speed involve heavy computations. We are seeking for an approach which involves easy computations and can avoid mathematical hazardous. Also, the wind speed in near future on the values of other meteorological variables in previous time such as humidity, temperature, pressure. Obtaining these values of these variables from a meteorological station is time consuming and increase complexity. So in this paper, we represent a new approach for wind speed prediction which involves less computation and makes use of only memory-based wind speed to predict the next step wind speed.

3. PROPOSED PREDICTION METHOD AND PERFORMANCE ANALYSIS

The fundamental idea behind our proposed prediction method is to use the observed data of wind speed in the near future. The method is based on the well-known fact of continuity of wind. More specifically this method makes use of current and previous wind speed information at a given location to generalize/forecast the future wind speed. Wind speed is continuously changing due to several factors. So the dynamic model that governs the behaviors of wind speed contains nonlinearities and uncertainties. Considering all, a simple dynamic model is assumed.

3.1 Memory Based Wind Speed Prediction

The dynamic model that characterizes the behavior of wind speed is expressed as

$$\dot{V} = f(V, t) \quad (1)$$

which could represent a generic model for wind speed variation. Using the Euler method (1) can be digitized as

$$V_{k+1} = V_k + Tf(\cdot) \quad (2)$$

where T is the sampling period (per unit), $V_{k+1} = V_k + Tf_k(\cdot)$ represents the wind speed at time instant $t_k = kT$ and $f_k(\cdot) = f(V_k, t_k)$ is the unknown wind model function.[1]

In the following section, we explore a method for wind speed prediction that only utilizes previously stored information about V (i.e. $V_k, V_{k-1}, \dots, V_{k-r}$) to achieve good prediction of the next step wind speed. For the

prediction problem to admit a feasible solution, we need to make the following assumption about $f(\cdot)$. Namely the wind speed under consideration satisfies the persistence condition in that for an integer $r \geq 1$ there exists a constant c_r such that

$$\sup_{f \geq 0} \left| \frac{d^r f(\cdot)}{dt^r} \right| \leq c_r < \infty \quad (3)$$

As long as the wind speed does not change drastically within a prediction time interval such an assumption seems justified in practice.

Note that the prediction algorithms as developed below do not involve c_r . As a result, no estimation of such a parameter is needed in implementing the method. [1]

3.1.1 Structure and Algorithms

To predict the value of V at time instant $t_{k+1} = (k+1)T$, we obtain the following predictor

$$Z_{k+1} = \phi_k^r(w, V_k, V_{k-1}, \dots, V_{k-r}) \quad (4)$$

where Z_{k+1} is the prediction of V_{k+1} , $w = [w_0, w_1, \dots, w_r]$

is the memory-coefficient to be determined, and $\phi_k^r(\cdot)$ is a mapping nonlinear/linear function to be specified. Here $r \geq 1$ is an integer real representing the order of the predictor (i.e. it indicates the number of previous data used in the algorithm). The overall predicting scheme is sketched in the following Figure 1.[1]

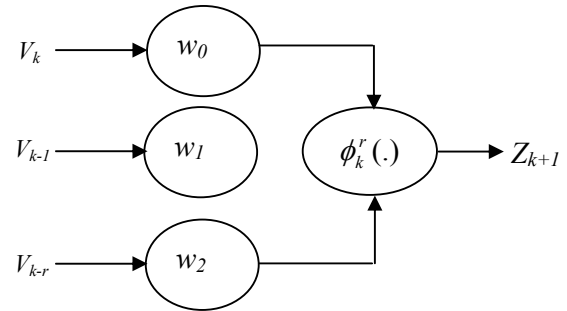


Fig 1: Memory based predictor

If a linear mapping function is used, we have the following r^{th} -order wind speed predictor

$$\begin{aligned} Z_{k+1} &= \phi_k^r(w, V_k, V_{k-1}, \dots, V_{k-r}) \\ &= \sum_{i=0}^r w_i V_{k-i} \end{aligned} \quad (5)$$

where the memory coefficients w_i satisfy following condition,

$$\sum_{i=0}^r w_i = 1 \quad (6)$$

It is obvious that for constant wind speed the proposed predictor gives perfect prediction in that the prediction error

$$\begin{aligned} e_{k+1} &= V_{k+1} - Z_{k+1} \\ &= V_{k+1} - \sum_{i=0}^r w_i V_{k-i} \\ &= \left(1 - \sum_{i=0}^r w_i\right) V \equiv 0 \forall k \geq 1 \end{aligned}$$

3.1.2 Performance Analysis

To show the effectiveness of the proposed predictor, we offer a brief analysis on the prediction performance in terms of prediction error. For the sake of simple notation, the r^{th} -order predictor is expressed as

$$Z_{k+1} = \phi_k^r \quad (7)$$

With the general predicting algorithm (7), the prediction error

$$\begin{aligned} e_{k+1} &= V_{k+1} - Z_{k+1} \\ &= V_k + Tf_k - \phi_k^r \end{aligned} \quad (8)$$

To retrieve the memorized information, we perform one-step backward time-shift in (8) to get

$$e_k = V_{k-1} + Tf_{k-1} - \phi_k^r \quad (9)$$

Subtracting (9) from (8), and using the fact that $e_k = V_k - \phi_{k-1}^r$ yields,

$$\begin{aligned} e_{k+1} &= e_k + T(f_k - f_{k-1}) - \phi_k^r + \phi_{k-1}^r + V_k - V_{k-1} \\ &= 2V_k - V_{k-1} - \phi_k^r + T(f_k - f_{k-1}) \end{aligned} \quad (10)$$

For the 1st-order predictor

$$Z_{k+1} = \phi_k^1 = w_0 V_k + w_1 V_{k-1} \quad (11)$$

where $w_0=2$ and $w_1=-1$ we have from (10) that

$$e_{k+1} = T(f_k - f_{k-1}) \quad (12)$$

With the assumption that f does not change infinitely fast, we have

$$\left| \frac{f_k - f_{k-1}}{T} \right| \leq \sup_{r \geq 0} \left| \frac{df}{dt} \right| \equiv c_1 \quad (13)$$

where c_1 is defined as in (13) for $r=1$. Therefore it follows from (12) and (13) that

$$|e_{k+1}| \leq T^2 c_1$$

i.e. bounded predicting error is achieved. Note that

$T \ll 1$ is the sampling period (per unit), a fairly good forecasting can be obtained by choosing T small [1].

4. PREDICTION TEST WITH REAL DATA

Real-time measurement of wind speed is necessary for predicting future wind speed. A series of computer simulation has been conducted with real wind speed data collected from a particular site at Chandona, Gazipur, a secured place owned by BUET. The data has been simulated for one hour average wind speed (km/hr) and thus got data for 27 days (29/12/2002 to 24/01/2003). To show the effectiveness of the proposed method, the first order predictor is used for prediction. Based on hourly wind speed variation, we simulate the algorithm for each time instance (the sampling period 1hour). The real wind speed and predicted wind speed are plotted together. For convenience, we represent our graphical plots in three different ways in Figures 2 to 4.

- Hourly variation within a day
- Hourly variation (averaged for 27 days)
- Daily mean variation

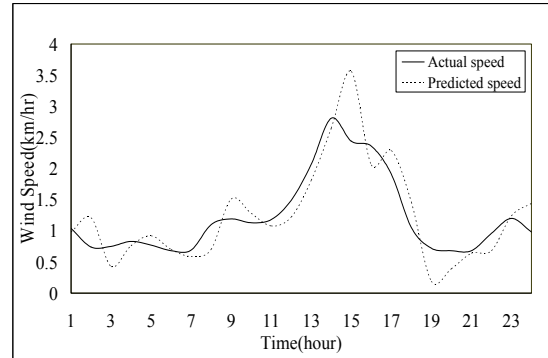


Fig 2: Hourly variation within a day (29/12/02)

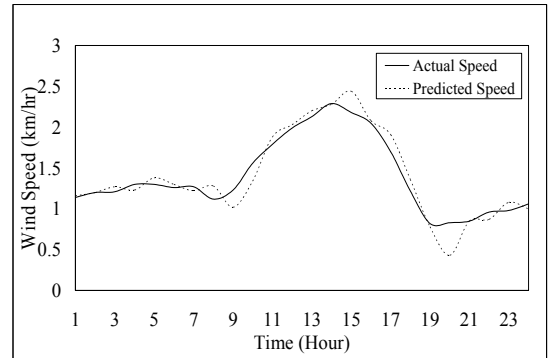


Fig 3: Hourly variation (averaged for 27 days)

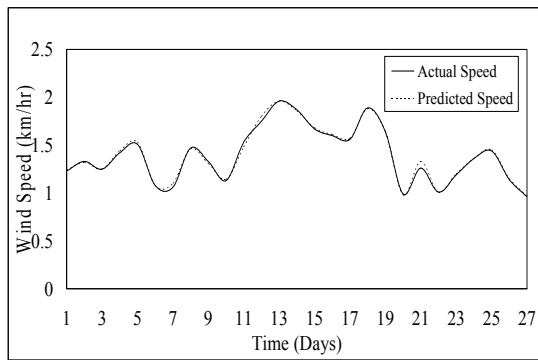


Fig 4: Daily mean variation

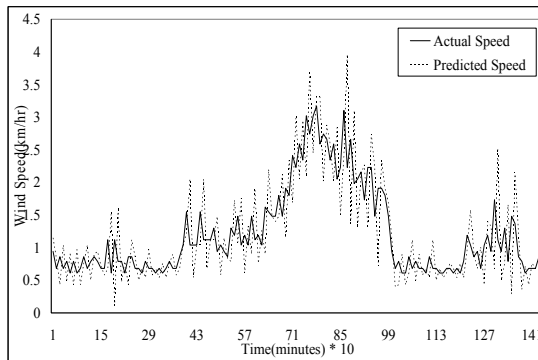


Fig 5: Speed variation with 10 minutes interval

5. DISCUSSION

Our proposed predicting algorithm is able to predict wind speed with a fairly good precision as long as the wind speed variation is not extremely brisk. It is effective in prediction when the sampling period is shortened. Simulation has been done for 1 hour sampling period. If this sampling period is reduced to 30 minutes or 10 minutes, a fairly good forecasting can be obtained. The Figure 5 shows predicted wind speed for 10 minutes interval using 1st order predictor. Using higher order predictor it can be achieved fairly good prediction than lower order predictors.

There exist a time lag between predicted wind speed curves and actual wind speed curves. Predicted wind speed curve does not follow the actual one, i.e. when actual wind speed tend to increase, the predicted wind speed may tend to decrease and vice versa. But the general trends are same for both cases. The proposed predicting algorithm is more effective for higher values of wind speed.

6. CONCLUSIONS

The philosophy involved here is that the wind speed at the time $t + \Delta t$ at a given location is related to its

current speed and its previous speed. In contrast to the traditional persistence method, the proposed approach does not assume that the future speed is equal to the current speed. Instead, we use current and previous speed at the same location to predict the next step speed. With only a limited number of 'Back Steps', the proposed method is shown to be able to forecast the next step wind speed with a reasonable accuracy. It is also worth mentioning that the proposed algorithms do not require a complex wind speed model. The only condition imposed here is that the wind speed does not change drastically. The proposed algorithm is verified for one location. It can be verified for other locations i.e. other wind perspective areas in Bangladesh, where the wind speed is higher in magnitude. The prediction algorithm that is used in this paper might be modified to minimize the deviation between the actual speed and predicted speed. The prediction is focused on-one step ahead in this paper. Extension of the result to multi-step prediction is a planned topic for further research.

7. REFERENCES

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8. NOMENCLATURE

| Symbol | Meaning | Unit |
|--------|----------------------|---------|
| V | Actual Velocity | (km/hr) |
| Z | Predicted Velocity | (km/hr) |
| w | Memory Co-efficients | |
| t | Time | hr |
| T | Sampling Period | sec |