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Comparison of Wind Averaging Conversions between Gust Factor and Statistical Approaches

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Abstract: This paper presents comparison of wind averaging conversions between gust factor and statistical approach for prediction of basic wind speed in Shan Regions. The maximum hourly wind speed data from 1993 to 2012 are collected from three meteorological stations namely, Taunggyi, Lashio and Kengtung. According to World Meteorological Organization (WMO) Guidelines, gust factor approach and statistical approach are used for converting between various wind averaging periods. In order to compare into speeds at a standard height of 10 m. From this study, it is found that annual maximum 10 min basic wind speeds using statistical approach are higher when compared with the corresponding values of gust factor for Shan Region.

Keywords: Wind Averaging Conversion, WMO guidelines, Gust Factor, Statistical Approach.

I. INTRODUCTION

The wind resistant design of buildings and structures rely upon basic design gust wind speed provisions in wind loading. Wind speed is a random variable which is affected by lots of factors such as geometric shapes, local topography, roughness of surrounding terrain, and elevations of ground surface. The easiest and most direct means of obtaining wind speed distribution in different locations is to set up a measurement station at each location. The wind speeds are measured by using anemometer. Basic wind speed is based on peak gust speed average over a short time interval and corresponds to 10 m height above the mean ground level in an open terrain [2]. Wind speed conversions to account for varying averaging periods only apply in the context of a maximum (peak gust) wind speed of a given duration observed within some longer interval. It is important that all wind speed values be correctly identified as an estimate of the mean wind or an estimate of a peak gust. Once the mean wind is reliably estimated, the random effects of turbulence in producing higher but shorter-acting wind gusts, typically of greater significance for causing damage, can be estimated using a “gust factor”.

The conversion assumes the mean wind speed and the peak gust wind speed are at the same height (e.g. the WMO standard observation height + 10 m) above the surface. The practice of “converting” between wind speeds that are obtained from different wind averaging periods (e.g. 10 min, 1 min, 2 min, 3 min etc) is only applicable if the shorter averaging period wind is regarded as a “gust”, i.e. the highest average wind speed of that duration within some longer period of observation [6]. In this study, the collected maximum hourly wind speeds are converted into 10 min gust wind speed (the highest average wind speed) using both gust factor and statistical approach for Shan Region, Myanmar.

II. LOCATION OF THE STUDY AREA

The region lies between north latitude 19˚ 18′ 47″and 24˚ 6′ 36″ and between east longitude 96˚11′ 31″ and 101˚ 6′ 23″. Shan Region covers 155,800 km^2 (60,155 sq mi), almost a quarter of the total area of Myanmar. Most of the Shan Region is a hilly plateau, the Shan plateau, which together with the higher mountains in the north and south forms the Shan Hills system. The elevation of Shan Hills is 2673 m (8770 ft) above sea level. The high plain averages about 1000 m (3300 ft) in elevation. Location of Shan Region is shown in the following figure:

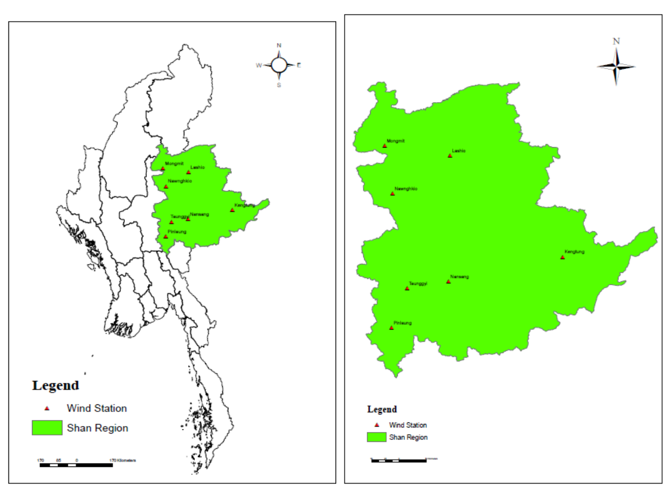

Figure1. Location of Shan Region in Myanmar.

III. BASIC WIND SPEED

Basic wind speed in the WMO guidelines is based on the 10 min average period at the standard reference height of 10 m above the ground level [6]. Table I summarizes the basic wind speed characteristics used, or recommended, in the six documents. In all cases the standard meteorological reference position of 10 m height in flat, open terrain is used [2].

TABLE I:
DEFINITIONS OF BASIC WIND SPEEDS [2]

Code	Averaging Time	Return Period (s)
ISO 4354	10-min	50-years
ENV 1991-2-4	10-min	50-years
ASCE 7-98	3-s	50-years
AIJ	10-min	100-years
AS 1170.2	3-s	20, 100-years
BS 6399: Part 2	1-h	50-years

IV. WIND AVERAGING CONVERSIONS (GUST FACTOR)

The WMO guidelines for estimating the mean wind is the 10 min average [6]. Wind speed time averaging conversions are used to transfer between estimates of mean wind speeds and peak gust wind speeds within a given observation period. In tropical cyclone context, the principally applied wind averaging conventions have been:

- The 10-min averaged mean wind (global);
- The 1-min "sustained" wind (USA), and
- The peak gust, nominally 2-sec or 3-sec.

The review of wind averaging methodologies is expected to help clarify the methods being applied within the different WMO regional associations, to better standardize and facilitate exchange of measured and estimated wind speeds and to update the Global Guide recommendations accordingly. In addition, the increasing amount of reliably measured wind speeds during TC conditions has provided an opportunity for comparing new data with accepted empirical wind turbulence models. The review firstly addresses the theoretical background to a simple statistical model of the near-surface wind environment. Using a variety of existing methods and data, recommendations are then made as to the appropriate method to be used for deriving wind averaging conversion factors for tropical cyclone conditions. The aim has been to provide a broad-brush guidance that will be most useful to the forecast environment rather than a detailed analytical methodology. Notwithstanding this, accurate wind prediction and measurement under all conditions (not just tropical cyclones) is a very difficult and challenging problem that requires careful consideration of a number of important matters such as local surface roughness, site exposure and topographic effects. Furthermore, instrument type and response can affect the interpretation of wind measurements.

A. The Near-Surface Wind

Conventionally, it is assumed that the actual wind can be considered as the sum of a mean wind and some turbulent components. From the observational perspective, the aim is to process measurements of the wind so as to extract an estimate of the mean wind and its turbulence properties. Typically these needs revolve around the concept of the mean wind speed and an associated gust wind speed. The difference between 1-s, 3-s, 1-min and 10-min observed means is solely that the longer averaging period leads to the sample mean being a more accurate estimate of the true mean. Provided that the sampling is random, the expected values for each averaging period are equal and individual realizations will be both greater and less than the true mean.

The "gust factor" is a theoretical conversion between an estimate of the mean wind speed and the expected highest gust wind speed of a given duration within a stated observation period. Wind averaging factors or gust factors are a convenient way to exploit the time-invariant statistical properties of the turbulent wind provided that (a) the flow is steady (or stationary in the statistical sense), (b) the boundary layer is in equilibrium with the surface roughness, and (c) the reference height is constant (+ 10 m). Converting between the mean and gust metrics can then proceed, but only on the basis of a single estimate of the mean wind. Hence, mean wind speeds per sec cannot be converted; only the most likely gust wind speeds of a given duration (τ) within a specific period of observation (T_o) of the mean wind can be estimated [7].

B. Recommended Procedure for Wind Speed Conversion

Wind speed conversions are possible only in the context of a maximum (gust) wind speed of a given duration observed within some longer interval, relative to the true mean wind speed. To ensure clarity in the description of wind speed, a nomenclature is introduced that will clearly describe and differentiate a gust from a mean, as follows: It is proposed that an estimate of the true mean wind V should be explicitly identified by its averaging period T_o in seconds, described as V_{T_o}, e.g.

V_{600} is a 10-min averaged mean wind estimate;
e V_{60} is a 1-min averaged mean wind estimate;
V_3 is a 3-sec averaged mean wind estimate.

Likewise, it is proposed that a gust wind should be additionally prefixed by the gust averaging period τ and be described as V_{τ,T_o}, e.g.

- $V_{60,600}$ is the highest 1-min mean (gust) within a 10-min observation period;
- $V_{3,60}$ is the highest 3-sec mean (gust) within a 1-min observation period.

The "gust factor" G_{τ,T_o} then relates as follows to the mean and the gust in the following equation;

$$V_{\tau,T_o} = G_{\tau,T_o} . V \tag{1}$$

Where, the true mean wind V is estimated on the basis of a suitable sample, e.g. V_{600} or V_{3600}. The recommended procedure is a practical interim solution until such time as increased data collection and analysis provides a more definitive description of the near-surface wind turbulent energy spectrum in various situations under tropical cyclone conditions. On this basis, Table II provides the recommended near-surface (+10 m) conversion factors G_{τ,T_o} between different wind averaging periods, where the duration τ of the gust observation is referred to a base reference observation period T_o and there is an estimate available of the true mean wind V.

TABLE II: RECOMMENDED WIND SPEED CONVERSION FACTORS FOR TROPICAL CYCLONE CONDITIONS [6]

Exposure at + 10 m	Reference Period T_o (s)	Gust Factor G_{τ,T_0} Gust Duration τ (s)		
		3	60	600
In-Land -roughly open terrain	3600	1.75	1.28	1.08
	600	1.66	1.21	1.00
	180	1.58	1.15	
	120	1.55	1.13	
	60	1.49	1.00	
Off-Land -offshore winds at a coastline	3600	1.60	1.22	1.06
	600	1.52	1.16	1.00
	180	1.44	1.10	
	120	1.42	1.08	
	60	1.36	1.00	
Off-Sea -onshore winds at a coastline	3600	1.45	1.17	1.05
	600	1.38	1.11	1.00
	180	1.31	1.05	
	120	1.28	1.03	
	60	1.23	1.00	
At-Sea -offshore >20 km	3600	1.30	1.11	1.03
	600	1.23	1.05	1.00
	180	1.17	1.00	
	120	1.15	1.00	
	60	1.11	1.00	

C. Estimating 10 min gust wind speeds from the hourly wind speed

The annual maximum wind speeds for 20 calendar years from 1993 to 2012 are collected from three meteorological stations in Shan Region namely, Taunggyi, Lashio and Kengtung. To predict basic wind speed, it is necessary to estimate the 10 min gust wind speed from hourly wind and at the standard reference height of 10 m above ground level. To estimate maximum 10 min gust wind speeds from hourly wind speeds, Equation 1 and TABLE II are used. For this research, gust factor $G_{600,3600}$ is taken as 1.08. The converted maximum 10 min gust wind speeds at 10 feet height are listed in TABLE III.

TABLE III: CONVERTED MAXIMUM 10 MIN GUST WIND SPEEDS AT 10 FEET HEIGHT

Year	Maximum 10 min gust wind speed (m/s)		
	Taunggyi	Lashio	Kengtung
1993	6.995	5.789	3.089
1994	7.333	5.789	3.089
1995	3.575	8.694	*
1996	6.998	4.633	2.030
1997	5.789	3.478	4.536
1998	5.843	2.322	4.061
1999	6.664	6.955	4.147
2000	6.955	4.633	4.061
2001	6.178	2.894	4.147
2002	8.208	2.894	4.061
2003	6.998	7.722	6.178
2004	4.104	4.633	4.061
2005	3.866	4.633	2.419
2006	11.534	4.633	2.894
2007	7.528	0.961	2.894
2008	4.633	2.322	1.447
2009	5.983	5.789	1.933
2010	4.730	7.722	2.419
2011	7.625	3.478	1.447
2012	3.812	11.588	2.894

D. Wind Speed Calculation for 10 m (33-ft) Standard Height

Wind speeds are needed at a height of 10 m for correlation with measured noise data as specified in ETSU-R-97 (Energy Technology Support Unit) [9]. The following equation is used to calculate a 10 m height wind speed from the hub height wind speed every 10 minutes with assuming roughness length (0.01) taken from Table IV.

$$U_1 = U_2 \frac{\ln\left(H_1/z\right)}{\ln\left(H_2/z\right)} \qquad (2)$$

Where,

H_1 = the height of the wind speed to be calculated (10 m)

H_2 = the height of the measured wind speed
U_1 = the wind speed to be calculated
U_2 = the measured wind speed
z = the roughness length (open, flat terrain)

ETSU-R-97 suggests the typical roughness lengths associated with different terrain types in the following Table IV [8].

TABLE IV: TYPICAL ROUGHNESS LENGTHS ASSOCIATED WITH DIFFERENT TERRAIN TYPES

Type of Terrain	Roughness Length, z
Water, snow or sand surfaces	0.0001
Open, Flat, mown grass	0.01
Farmland with vegetation (reference conditions)	0.05
Suburbs, towns, forests, many trees and bushes	0.3

The converted maximum 10 min gust wind speeds at the standard height 10 m (33-ft) are described in TABLE V.

TABLE V: CONVERTED MAXIMUM 10-MIN GUST WIND SPEEDS AT THE STANDARD HEIGHT 10 M (33-FT)

Year	Maximum 10 min gust wind speed (m/s)		
	Taunggyi	Lashio	Kengtung
1993	8.402	6.993	3.732
1994	8.585	6.993	3.732
1995	4.319	10.502	*
1996	8.454	5.597	2.452
1997	6.993	4.201	5.479
1998	7.058	2.805	4.906
1999	8.050	8.402	5.010
2000	8.402	5.597	4.906
2001	7.463	3.496	5.010
2002	9.915	3.496	4.906
2003	8.454	9.328	7.463
2004	4.958	5.597	4.906
2005	4.670	5.597	2.922
2006	13.933	5.597	3.496
2007	9.094	1.161	3.496
2008	5.597	2.805	1.748
2009	7.227	6.993	2.335
2010	5.714	9.328	2.922
2011	9.211	4.201	1.748
2012	4.605	13.998	3.496

V. WIND AVERAGING CONVERSIONS (STATISTICAL APPROACH)

Statistical and probabilistic approach is used to derive formula for estimating 10 min gust wind speeds from hourly wind speeds.

A. Normal distribution

The normal or Gaussian distribution is the most important of all the distributions since it has a wide range of practical applications. The cumulative distribution function of X can now be found by using the following equations;

$$F(z) = \text{probability } (Z \le z) \tag{3}$$

$$F(z) = \text{probability } \left(\frac{x-\mu}{\sigma} \le z\right) \tag{4}$$

$$F(z) = \text{probability}(X \le \mu + z\,\sigma) \tag{5}$$

B. Proposed Formula for converting 10 min gust wind speeds

For 10 min gust wind speed over an hourly period, the probability is 10/3600 or 0.28% (0.0028), therefore from statistics [10], Equations 6 and 7 are obtained.

$$u_{10min} = u_{1hr} + z\sigma \tag{6}$$

Or

$$u_{10min} = u_{1hr}\left[1 + {z\sigma_u}/{u_{1hr}}\right] \tag{7}$$

Where, u_{10min} is the 10 min gust wind speed, u_{1hr} is hourly mean wind speed and σ_u is the standard deviation of the u_{1hr}. In most cases, the gust factor (e.g.u_{10min}/u_{1hr}) can be described as Equation 8 using models developed for standard neutral boundary layer flow conditions [5] and according to Arya,

$$\sigma_u = 2.5u_* \tag{8}$$

Where σ_u is standard deviation and u_* is the friction velocity. Furthermore, the friction velocity can be expressed as in Equation 9 according to Electronic Journal of Structural Engineering [4].

$$\frac{u_*}{u_{1hr}} = kp \tag{9}$$

Where k = 0.4 is the von Karman constant and p is the exponent of the power-law wind profile [3]. Now, by substituting Equation 8 and Equation 9 into Equation 7, the following equations are obtained:

$$u_{10min} = u_{1hr}\left[1 + z\frac{2.5u_*}{u_{1hr}}\right] \tag{10}$$

$$u_{10min} = u_{1hr}\left[1 + z.p\right] \tag{11}$$

Equation 11 is the formula for estimating the 10 min gust wind speed from hourly wind speed. In order for the engineers to have a better estimation of p from Z_o of Figure 2 is provided. For example, for an open terrain where Z_o = 0.02m, p=0.155 [4].

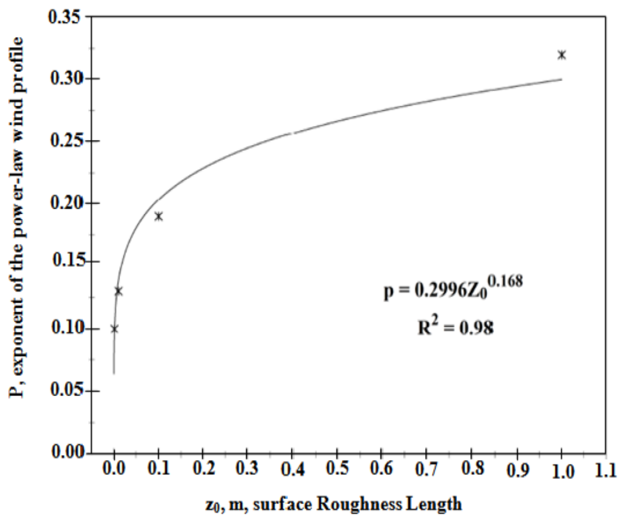

Figure 2. Relationship between Z_0 and p [3].

To predict basic wind speed, formula for estimating maximum 10 min gust wind speeds from hourly mean wind speeds, Equation 11 is used. Different terrains can be categorized according to their associated roughness length, Z_o. So, Z_o of open terrain is 0.02 [1]. The converted annual maximum 10 min gust wind speeds at 10 feet height for all three stations are tabulated in TABLE VI.

TABLE VI: CONVERTED ANNUAL MAXIMUM 10 MIN GUST WIND SPEEDS FOR TAUNGGYI, LASHIO AND KENGTUNG

Year	Maximum 10 min gust wind speed (m/s)		
	Taunggyi	Lashio	Kengtung
1993	7.818	6.515	3.474
1994	8.252	6.515	3.474
1995	4.017	9.772	*
1996	7.872	5.212	2.280
1997	6.515	3.909	5.103
1998	6.569	2.606	4.560
1999	7.492	7.818	4.669
2000	7.818	5.212	4.560
2001	6.949	3.257	4.669
2002	9.229	3.257	4.560
2003	7.872	8.868	6.949
2004	4.615	5.212	4.560
2005	4.343	5.212	2.714
2006	12.975	5.212	3.257
2007	8.469	1.086	3.257
2008	5.212	2.606	1.629
2009	6.732	6.515	2.172
2010	5.320	8.686	2.714
2011	8.578	3.909	1.629
2012	4.289	13.029	3.257

The converted maximum 10 min gust wind speeds at the standard height 10 m (33-ft) for three stations are summarized in TABLE VII.

TABLE VII: CONVERTED ANNUAL MAXIMUM 10-MIN GUST WIND SPEEDS FOR TAUNGGYI, LASHIO AND KENGTUNG

Year	Maximum 10 min gust wind speed (m/s)		
	Taunggyi	Lashio	Kengtung
1993	9.442	7.867	4.196
1994	9.966	7.867	4.196
1995	4.852	11.802	*
1996	9.507	6.294	2.754
1997	7.868	4.721	6.163
1998	7.933	3.147	5.508
1999	9.048	9.442	5.639
2000	9.442	6.294	5.508
2001	8.392	3.934	5.639
2002	11.146	3.934	5.508
2003	9.507	10.491	8.392
2004	5.573	6.294	5.508
2005	5.245	6.294	3.278
2006	15.670	6.294	3.934
2007	10.228	1.311	3.934

2008	6.294	3.147	1.967
2009	8.130	7.867	2.623
2010	6.425	10.491	3.278
2011	10.359	4.721	1.967
2012	5.179	15.736	3.934

VI. COMPARISON OF GUST FACTOR AND STATISTICAL APPROACH

The comparison of wind averaging conversion for maximum 10 min gust wind speed between gust factor approach and statistical approach are provided in the following table and figures.

TABLE VIII: COMPARISON BETWEEN MAXIMUM 10-MIN GUST WIND SPEEDS USING GUST FACTOR AND STATISTICAL APPROACH

Year	Maximum 10 min gust wind speed (m/s)					
	Taunggyi		Lashio		Kengtung	
	Gust Factor	Statistical approach	Gust Factor	Statistical approach	Gust Factor	Statistical approach
1993	8.40	9.442	6.99	7.867	3.73	4.196
1994	8.59	9.966	6.99	7.867	3.73	4.196
1995	4.32	4.852	10.50	11.80	*	*
1996	8.45	9.507	5.59	6.294	2.45	2.754
1997	6.99	7.868	4.20	4.721	5.47	6.163
1998	7.09	7.933	2.81	3.147	4.91	5.508
1999	8.05	9.048	8.402	9.442	5.01	5.639
2000	8.40	9.442	5.59	6.294	4.91	5.508
2001	7.46	8.392	3.50	3.934	5.01	5.639
2002	9.92	11.146	3.50	3.934	4.91	5.508
2003	8.45	9.507	9.33	10.491	7.46	8.392
2004	4.96	5.573	5.59	6.294	4.91	5.508
2005	4.67	5.245	5.59	6.294	2.92	3.278
2006	13.93	15.670	5.59	6.294	3.50	3.934
2007	9.09	10.228	1.16	1.311	3.50	3.934
2008	5.59	6.294	2.81	3.147	1.75	1.967
2009	7.23	8.130	6.99	7.867	2.34	2.623
2010	5.71	6.425	9.33	10.491	2.92	3.278
2011	9.21	10.359	4.20	4.721	1.75	1.967
2012	4.61	5.179	13.99	15.736	3.50	3.934

From TABLE VIII, it may be noted that annual maximum 10 min gust wind speeds using Statistical Approach are higher when compared with the corresponding values of Gust Factor for Shan Region, Myanmar.

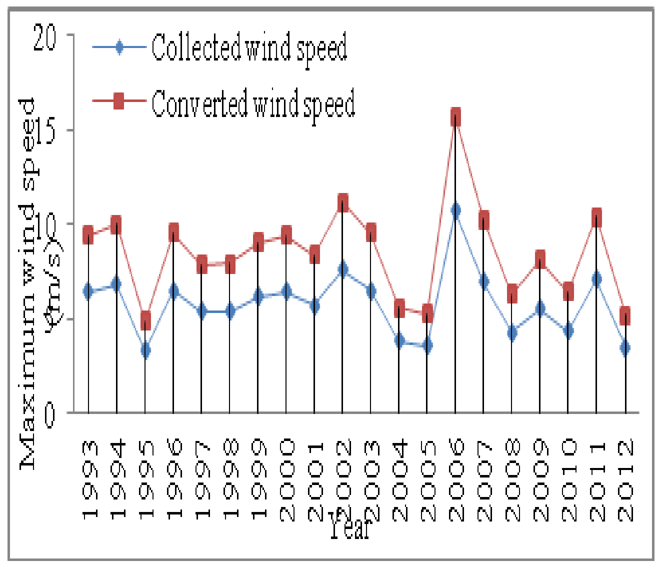

Figure 3.Maximum 10 min gust wind speed for Taunggyi.

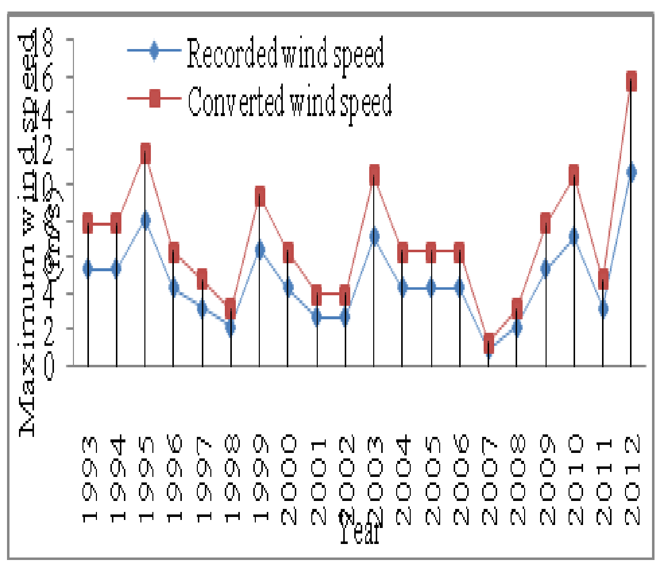

Figure 4.Maximum 10 min gust wind speed for Lashio.

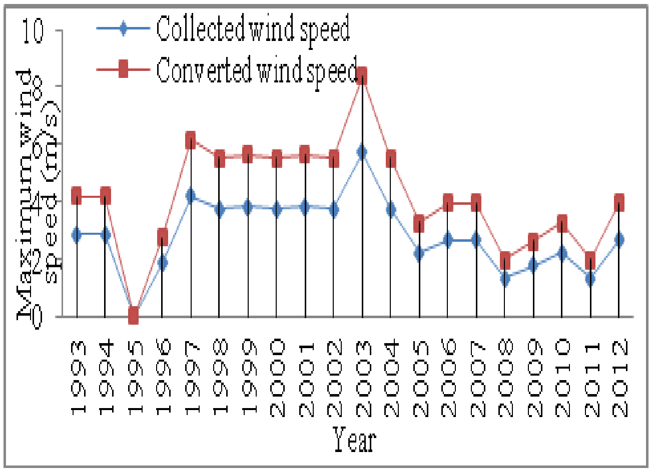

Figure 5.Maximum 10 min gust wind speed for Kengtung.

VII. DISCUSSION AND CONCLUSION

The paper presented the procedure for estimation of maximum 10 min gust wind speeds from hourly wind data using Gust Factor and Statistical Approach. According to WMO Guidelines, gust factor approach and statistical approach are used for converting between various wind averaging periods. In order to compare wind averaging conversions, the collected maximum hourly wind speeds are converted into 10 min gust wind speeds at a standard height of 10 m using both gust factor and statistical approach for Shan Region, Myanmar. For this study, gust factor $G_{600,3600}$ is taken as 1.08 to convert maximum 10 min gust wind speed from hourly wind and the value of roughness length is also taken as 0.01 to calculate 10 m standard height in open and flat terrain. It is observed that the maximum values obtained from Statistical Approach when compared the values of Gust Factor are chosen to estimate the wind speed distribution models for Shan Region. More reliable results can be obtained by using historical wind speed data.

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IX. REFERENCES

[1] AS/NZS 1170.2:2002, Standards Australia/Standard, "Structural Design Action, Part 2 Wind Actions".

[2] J.D.Holmes, "Wind Loading of Structures", Spon Press, London, UK, 2001.

[3] Justus,C.G., "Wind Energy", in Handbook of Applied Meteorology, D.D.Houghton (Ed.), Chapter 33,John Wiley & Sons, N. Y., 1985, pp.915-944.

[4] S.A.Hsu, Coastal Studies Institute, Louisiana State University, Baton Rouge Louisiana, USA, "Estimating 3-second and maximum instantaneous gusts from 1-minute sustained wind speeds during a hurricane".

[5] Vickery, P. J. And Skerlj. P. F., "Hurricane Gust Factors Revisited", J.Strucural Engineering – ASCE, Vol. 131, No. 5, May 2005, pp.825-832.

[6] B.A.Harper[1], J.D.Kepert[2] and J.D.Ginger[3], "World Meteorological Organization Guidelines For Conversions between Various Wind Averaging Periods In Tropical Cyclone Conditions", WMO, October 2008.

[7] WMO 1993: Global guide to tropical cyclone forecasting. Tropical Cyclone Programme Report No.TCP-31, World Meteorological Organiztion, WMO/TD-No.560, Geneva.

[8] TNEI Services Ltd, "HMP Standford Hill Wind Energy Development Environmental Impact Assessment-Noise & Vibration", Appendix 8.6-Wind Speed Calculations, December 2010.

[9] DTI Noise Working Group (1996). The Working Group on Noise from Wind Turbines: "The Assessment and rating of Noise from Wind Farms, ETSU Report ETSU-R-97.

[10] Christopher Chatfield, Penguin Books, "Statistics for Technology", 1970.