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Effect of Power Deviation Ratio on the Selection of Sites for a Wind Power Generation System

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***ABSTRACT**: Wind energy is one of the most important energy among the renewable energy sources in today's world. Realizing the importance of renewable energy, this paper focuses on selecting sites to harvest electrical power from wind energy as the demand of electricity is on increase rapidly. In this work, precisely, seven different regions of Bangladesh with high average of yearly wind speed are investigated. The results of the investigations show the relation between Unit Electricity Cost of a typical site with the power deviation ratio of generating power with respect to average load of that site. This relation helps to select a site to set up wind power generation system not only considering high average speed of wind and high average generated power as key-factors but also to consider power deviation ratio of the site in order to justify the system economically.*
***Keywords:** BOS, LCCA, Power Deviation Ratio, TSR, UEC.*

I. INTRODUCTION

Power is the pre-condition for social and economic development. But currently consumers cannot be provided with uninterrupted and quality power supply due to inadequate generation of electricity compared to the national demand. In 1971, 3% of the total population in Bangladesh had access to electricity. Total installed electricity capacity by December, 2014, is 10,817 MW of which 5,880 MW (54%) comes from public sectors and 4,937 MW (46%) comes from private sectors of Bangladesh [1]. By 2014 only 55.20% of total population of Bangladesh had access to electricity [2]. This statistic of consumers of electricity clearly shows that some percentage of total population of Bangladesh still cannot access electricity due to the shortage of power generation. To resolve the present shortfall and to meet the increasing demand for electricity, the government has taken an initiative to increase generation (installed) capacity to 13735 MW by 2015[3].

Power generation is Bangladesh was almost mono-fuel dependent, meaning indigenous natural gas considering it's apparent huge availability. But 89% of power previously used to come from natural gas and the rest is from liquid fuel, coal and hydropower [3]. But by burning fossil fuel emits carbon di oxide, nitrogen oxide, sulphur di oxide and other toxic materials and gases into our atmosphere directly causing environmental degradation and health hazards.

Renewable energy helps in reducing energy shortage, environmental degradation. In recent years, the development of renewable energy is one of the important strategies adopted as part of Fuel Diversification Program. Renewable Energy Policy has been approved in 2008. Through this policy the government commits to facilitate both public and private investment in renewable energy projects to substitute indigenous non-renewable energy supplies and boost up contributions of existing renewable energy like solar, hydro, wind energy based electricity productions. The policy targets to be able to generate 5% of the total generation of electricity from renewable sources by 2015 and 10% of the same by 2020 [3].

Wind energy is one of the main resources among renewable sources. Site selection of a country is the main challenge to set up a wind power generation station. Usually sites having high wind speeds are considered for the development of wind power generation station. But it has been found that selection of a site depending on high wind speed is not always economically feasible. Power deviation ratio plays a vital role in this regard and so in this paper seven different sites or regions of Bangladesh having high annual average wind speed are taken to demonstrate this phenomenon. The annual average wind speed profile of the sites are obtained by averaging the wind speeds over last ten years. The deviations of generating wind power are investigated with respect to the loads of the respective regions. In this work, average power of the respective sites are considered as their loads. Unit electricity cost (UEC) of wind power generation system over twenty years of life cycle of these eight regions are also computed. The results of these investigations depicts that the Unit Electricity Cost (UEC) of the power station of a typical site increases with the increase of the power deviation ratio of generating power of that site and vice-versa. This means that the high wind speed of a selected region may not be consistent over a particular time period and may vary and thus producing varying power which in turn varies the deviation of power with respect to average power i.e. our load for that particular site or region.

II. STATISTICS OF WIND SPEED

Seven sites considered for the purpose of analysis are, Barisal, Chittagong, Cox's Bazar, Dhaka, Jessore, Khepupara and Syedpur. The Statistics of monthly wind speeds of the regions are computed from averaging the monthly wind speeds over last ten years. These statistics are demonstrated in Table I and also shown graphically in Fig. 01.

Table I: Statistical Data of Wind Speed in m/s

Months	*Barisal*	*Chittagong*	*Cox's Bazar*	*Dhaka*	*Jessore*	*Khepupara*	*Syedpur*
January	5.31	8.83	6.66	4.53	8.24	5.63	6.17
February	5.73	10.05	7.94	4.97	8.69	6.06	7.91
March	6.39	10.28	7.67	5.99	10.77	7.71	7.67
April	7.23	10.4	8.21	5.61	11.87	8.24	6.62
May	7.19	10.08	7.85	5.52	12.2	8.16	6.35
June	6.17	11.03	7.86	4.59	11.18	8.34	6.33
July	5.7	11	7.13	4.82	9.98	7.77	6.35
August	5.42	9.8	7.7	4.59	9.84	7.94	6.42
September	6.26	8.9	7.29	5.42	9.63	7.94	6.17
October	5.81	7.63	6.77	5.43	11.54	6.6	6.68
November	4.86	8	6.32	4.35	8.72	4.76	6.06
December	3.69	7.75	6.27	4.07	6.83	5.28	5.87
Yearly avg. in m/s	5.81	9.48	7.31	4.99	9.96	7.04	6.55

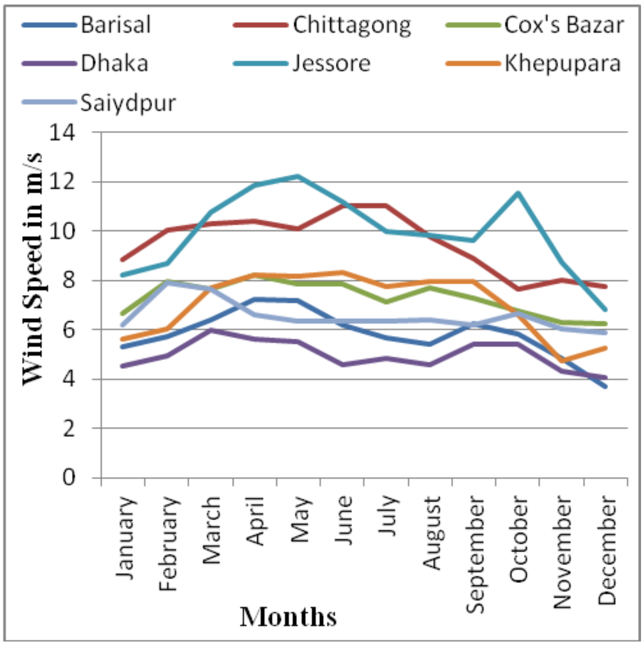

Figure 01: Wind speed variation in different months of various sites

The bar diagram of the comparison of annual average wind speed of the sites is shown in Fig. 02 and from this figure it can be seen that highest average wind speed 9.96 m/s is in Jessore where Chittagong come in second highest with average wind speed of 9.48 m/s. Dhaka the capital of Bangladesh has the lowest average wind speed of 4.99 m/s among these sites.

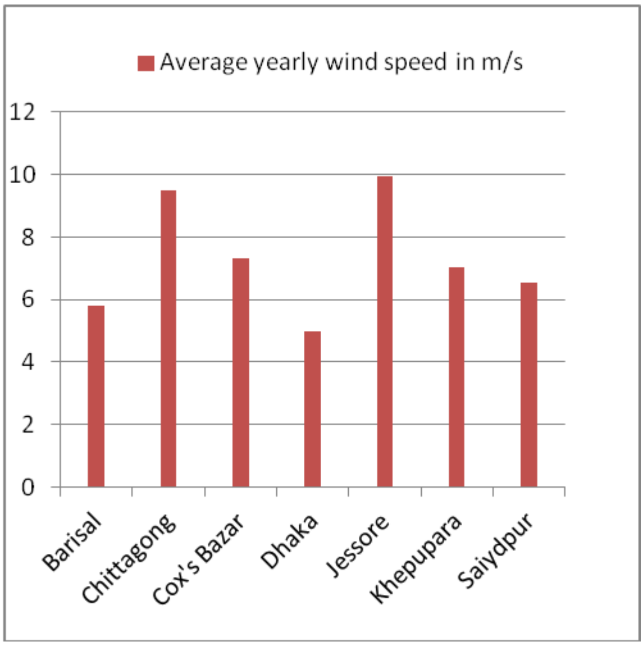

Figure 02: Comparison of annual average wind speed of various sites.

III. MODELING OF WIND POWER GENERATION SYSTEM

Setup of wind power generation system depends on the modeling of wind turbine and the sizing of batteries which are discussed below:

3.1 WIND TURBINE MODELING

The wind turbine considered is this paper has mechanical power (P_m) captured by the blades is described below [4]:

$$P_m = \frac{1}{2} C_p(\beta, \lambda)\rho\pi R^2 V_{wind}^3 \quad (1)$$

where, $C_p$is a rotor power coefficient, β is a blade pitch angle, λ is a tip-speed ratio(TSR), ρ is an air density, R is the radius of the wind turbine blade and V_{wind} is a wind speed. The rotor power coefficient is defined by the fraction of the available wind power that can be transformed to mechanical power by a rotor [5]. This rotor power coefficient (C_p) depends on the rotor blade aerodynamics, which is the function of a blade pitch angle (β) and a TSR (λ) [6], [7]. The type of a wind turbine rotor may also be another factor affecting the rotor power coefficient (C_p). However, the C_p of [7] in which a general blade type was assumed is used in this study for the sake of simplicity [6].

$$C_p = (0.44 - 0.0167\beta) \, Sin \frac{\pi(\lambda - 2)}{13 - 0.3\beta} - 0.00184(\lambda - 2)\,\beta \quad (2)$$

The maximum value of $C_p$can be of 44%. For the simplicity, C_p's value is considered as 30% in this study. The wind turbine specifications [8] used for the aid of analysis in this paper, are given the following Table II.

Table II: Parameters and Specification of the Wind Turbine Model

Parameter name	***Value***	***Unit***
Rated Power	600	Watt
Rotor diameter	1.73	M
Start-up wind speed	2.5	m/s
Rated wind speed	12	m/s
Survival wind speed	35	m/s
Tower height	6	m
Air density	1.225	Kg/m^3

The mechanical power (P_m) captured by the wind turbine does not fully convert to electrical power due to several losses occurring during the conversion in the machine. So taking into account the power losses, to obtain output electrical power of the generator from the mechanical wind power, the mechanical power ought to be multiplied by a factor named efficiency (η) of the generator. The electrical output power (P_e) of wind generator is described below:

$$P_{e,gen} = \eta P_m \tag{3}$$

here, the generator efficiency (η) is considered 78% in this study. The average power (P_{avg}) over a particular time period of a particular site is computed as follows:

$$P_{avg} = \frac{1}{n}\sum_{n=1}^{12} P_{e,gen}(n) \tag{4}$$

where, *n* is the number of months of a year in this study. The output powers of the generator of the seven sites under consideration is computed using equation (3) and the average powers of the sites are found using the equation (4). For comparative analysis of the powers of the sites, the data are given in Table III as follows:

Table III: Generated and average generated powers (in Watt) of seven sites

Months	*Barisal*	*Chittagong*	*Cox's Bazar*	*Dhaka*	*Jessore*	*Khepupara*	*Syedpur*
January	16.056	73.8306	31.6794	9.9689	59.9979	19.1372	25.1889
February	20.1752	108.856	53.6804	13.1651	70.3742	23.8656	53.0742
March	27.9806	116.502	48.3883	23.0481	133.9681	49.1493	48.3883
April	40.5293	120.6297	59.3449	18.934	179.352	59.9979	31.112
May	39.8603	109.8337	51.8756	18.0373	194.7304	58.2673	27.4584
June	25.1889	143.9066	52.0741	10.3703	149.8579	62.2089	27.1998
July	19.86	142.7356	38.8707	12.0087	106.5972	50.3057	27.4584
August	17.0747	100.9328	48.9583	10.3703	102.1738	53.6804	28.3765
September	26.3074	75.6004	41.5467	17.0747	95.7708	53.6804	25.1889
October	21.0321	47.6352	33.2752	17.1693	164.8055	30.8309	31.9657
November	12.3101	54.9065	27.0711	8.8272	71.1056	11.5658	23.8656
December	5.3881	49.9182	26.4336	7.23	34.1677	15.7854	21.6904
Yearly avg. Power in Watt	22.6469	95.4406	42.7665	13.8503	113.5751	40.7062	30.9139

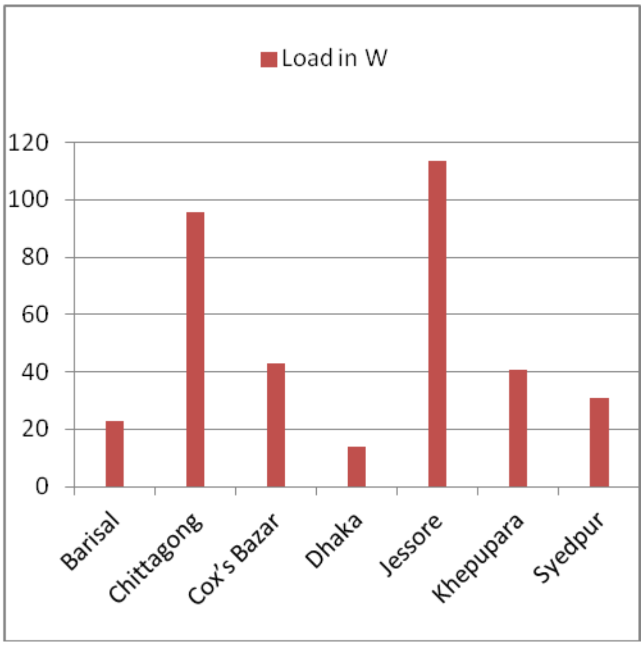

Figure 03 : Comparison of annual average power (i.e. also load in this study) of seven sites

The load (P_{load}) of a site is assumed to be equal to the produced average electrical power (P_{avg}) , for the sake of simplicity of this work and expressed mathematically as follows:

$$P_{load} = P_{avg} \tag{5}$$

For clear and comparative understanding, the annual average power which is also happen to be the load as discussed above, of the sites are plotted in a bar diagram Fig. 03 from where it becomes obvious that the highest annual average wind power is produced in Jessore and after Jessore, Chittagong has the second highest annual average wind power. Dhaka has minimum average power of 13.8503 W among these sites.

The output power of the wind generator varies with the variation of wind speed which causes power deviation. The papers prime find outs is the relation between unit electricity cost with the power deviation ratio of a particular site. This power deviation ratio over a particular time period of a site is the difference between the maximum power produced by the wind generator and the minimum power produced by the same, to the average load of that site. It is expressed in percentage. The produced powers are found using equation number (3). The definition of power deviation ratio is expressed mathematically by the following equation:

$$\text{Power Deviation Ratio} = \frac{P_{e\,(max)} - P_{e\,(min)}}{P_{load}} \times 100 \tag{6}$$

where, $P_{e\,(max)}$, $P_{e\,(min)}$ is the maximum and minimum electrical powers respectively, produced by the wind generator over a particular time interval of a site. The greater the numerator of the ratio with respect to P_{load}, the greater is the Power deviation ratio. The power deviation ratios of seven sites under consideration are calculated using equation (6) are presented in Fig. 04.

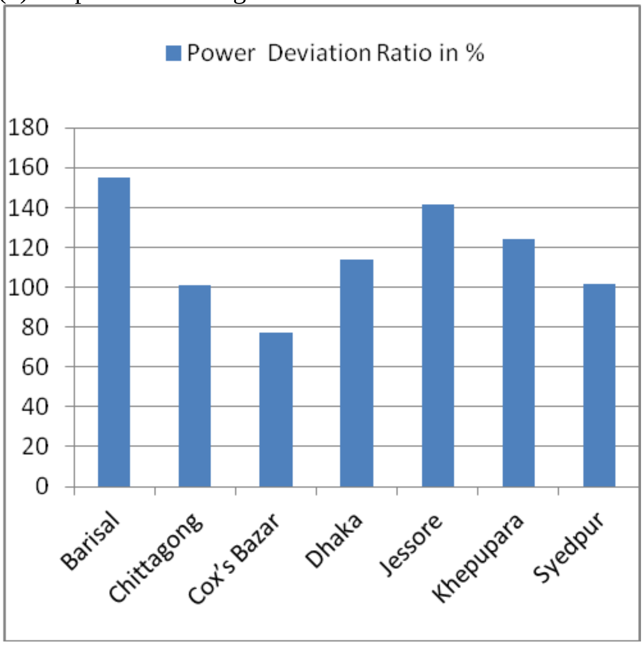

Figure 04: Power Deviation Ratio of seven sites

3.2 BATTERY SIZING

The generated and demanded energy (E_{gen} , E_{dem}) over a month period can be written in terms of the generated wind power and the power demand as follows:

$$E_{gen}(n) = P_{e.gen}(n)\,\Delta T \tag{7}$$

$$E_{dem}(n) = P_{e.dem}(n)\,\Delta T \tag{8}$$

where, $P_{e.gen}$ and $P_{e.dem}$ are the power generated by a specific wind turbine and power demand, respectively, of a site. n is the sampling time (months of a year), and ΔT is the time between the samples (in this case one month).

$$\Delta E(n) = E_{gen}(n) - E_{dem}(n) \tag{9}$$

On an average month, the battery is required to cycle between the positive and negative peaks of the energy curve obtained using equation (9). Therefore, the battery should at least have a capacity equal to the difference between the positive and negative peaks of the energy curve. For this type of application batteries designed specifically for cycling should be used. These batteries have a life time about 1500 cycles, and in order to obtain this life time, they should not be cycled through more than 80% of their rated capacity [9]. Hence, the number of batteries required for the needed storage capacity can be found as follows [10]:

Required Storage Capacity $=\Delta E(n)_{max} - \Delta E(n)_{min}$ (10)

Number of batteries, $N_b = \frac{required\ storage\ capacity}{(0.8)(rated\ capacity\ of\ each\ battery)}$ (11)

The rated capacity of each battery is defined as follows:

Rated capacity of battery $= V_b I_b$ (12)

where, V_b is the voltage of the battery, I_b is the ampere-hour of the battery. In this study 12V, 200Ah battery ratings are considered. The numbers of battery needed in seven different sites are list in Table IV.

Table IV: List of Number of batteries of seven sites

Region	*Total number of battery needed*	*Number of battery per Watt load*
Barisal	14	0.618186
Chittagong	37	0.387676
Cox's Bazar	13	0.303976
Dhaka	06	0.433204
Jessore	61	0.53709
Khepupara	19	0.466759
Syedpur	12	0.388175

IV. UNIT ELECTRICITY COST (UEC) ANALYSIS

Unit Electricity Cost (UEC) is the cost which is required to produce per kWh electricity. To calculate UEC, the total Life Cycle Cost Analysis (LCCA) of the power system has to be assessed. LCC covers the total cost of a power source in three phases: construction phase, operational phase and decommissioning phase. The construction phase includes the initial investment cost. Operational phase contains the fuel cost and the cost incurred due to operation and maintenance. The decommissioning phase covers the cost related to termination of the project and disposal of the equipment. All these costs are summed up to provide the total life cycle cost of the project. The overall cost incurred over the lifetime is then converted into unit cost per kWh of energy.

As Life Cycle Cost Analysis comprises not only the initial cost of a project but also all future costs for the entire operation of a system, the Net Present Value (NPV) of the components has to be taken into account. For this reason, all future costs are discounted in LCCA to their equivalent value in the present economy and the present worth of the costs is calculated. Thus the LCC analysis takes into account the changing value of money as well as cost escalations due to inflation.

The total annual cost for the wind power generation system is obtained considering the price of each component and the installation and other costs known as " Balance of System Cost" (BOS cost) given in Table V. In this study the BOS cost is taken as 25% of the cost of wind turbine. Therefore, to account for this cost, the cost of wind turbine is multiplied by 1.25 [10].

Table V: System component ratings and costs

Component	*Rating*	*Price (BDT)*	*BOS cost*
Wind Turbine	1 kW	37,000	25% of price
Deep Cycle Battery	2.4 kWh	17500	0

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To obtain the compound interest factor needed for calculating the annual cost [11], an interest rate of 6% was used. Also, a life expectancy of 20 years was assumed for the wind turbine [12] and a life expectancy of 4 years for the batteries. For simplicity of the study, single wind turbine is used in this power generation system.

Present value of 20 years of wind turbines :

C_{wind}= *(1.25)(Wind turbine cost in BDT/Turbine)* (13)

Present value of 20 years of maintenance of wind power generation system :

C_{main}=*(1.56 BDT/kWh)(Wind power generated kWh/Turbine/day)(365days/year)(11.4699 years compound interest factor)* (14)

Present value of the cost of batteries for 20 years :

$C_{battery}$= *(No. of batteries) (17500 BDT/ battery) (5 instalments over 20 years)* (15)

Present value of total capital cost :

$$C_{capital} = C_{wind} + C_{battery} \quad (16)$$

Present value of depreciation of the components of the wind power generation system over 5 years assuming a 30% tax bracket and an interest rate of 6% :

$$C_{Dep.} = [(C_{capital})\ (4.213 \text{ compound interest factor})\ (0.3)]/5 \quad (17)$$

Present value of actual cost of the power system :

$$C_{actual} = C_{capital} + C_{main} - C_{Dep.} \quad (18)$$

Unit Electricity Cost :

UEC = Cost/kWh

$$= [(C_{actual})\ (0.08718 \text{ compound interest factor})] / (\text{ Annual average wind generation in kWh }) \quad (19)$$

UEC of seven sites under consideration in this paper is calculated using equations from (13) to (19) and given in the Table VI.

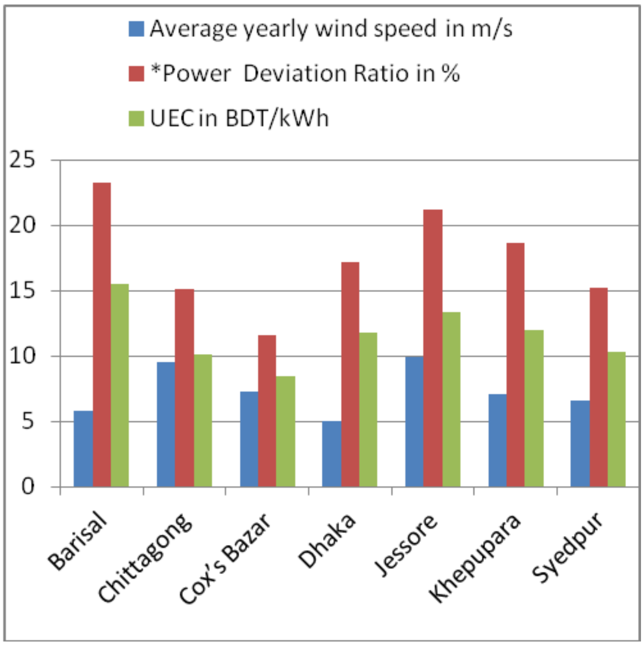
Table VI: Cost analysis of seven sites and UEC

Sites	C_{wind} (BDT)	C_{main} (BDT)	$C_{battery}$ (BDT)	$C_{capital}$ (BDT)	$C_{Dep.}$ (BDT)	C_{actual} (BDT)	UEC (BDT/kWh)
Barisal	46250	106490	1225000	1271250	321350	1056400	15.4743
Chittagong	46250	448790	3237500	3283750	830070	2902500	10.0885
Cox's Bazar	46250	201100	1137500	1183750	299230	1085600	8.4211
Dhaka	46250	65128	525000	571250	144400	491980	11.7836
Jessore	46250	534060	5337500	5383750	1360900	4556900	13.3100
Khepupara	46250	191410	1662500	1708750	431940	1468200	11.9653
Syedpur	46250	145370	1050000	1096250	277110	964510	10.3500

V. RESULTS AND DISCUSSIONS

For better understanding of the results obtained so far and to comment about them a comparison of annual average wind speed, power deviation ratio and UEC of the seven sites under consideration are plotted in Fig. 05. Only the power deviation ratios in Fig. 05, are reduced by 80% from their actual value (shown in Fig. 04) with an intention to provide better visual understanding of the pattern of the ratios. Therefore, the values of the ratios are multiplied with 0.2 and then plotted. But other parameters of the same figure, like annual average wind speeds and UECs are plotted with their actual values.

Among the seven sites, in Jessore the highest annual average wind speed flows with a value of 9.96 m/s and the next best site with high average wind speed is Chittagong where an average of 9.48 m/s of wind flows. The average wind speed of Cox's Bazaar is 7.31 m/s. These are top three regions with high average wind speeds among the sites chosen for this study. A general concept of choosing a site to construct a wind power station is that a location with high wind speed record is good for the purpose to generate greater power. Though this concept is highly appreciable, but to setup a power station which is economically also good would be a better idea. As can be seen from Fig. 05, Jessore has highest average wind speed among Chittagong and Cox's Bazar. But to produce electricity using wind power in Jessore, 13.31 BDT/kWh is required where in Chittagong UEC of 10. 9 BDT/kWh and in Cox's Bazaar 8.42 BDT/kWh are required. Where there is highest average wind speed is in Jessore, it requires more costs than costs requires in Chittagong and Cox's Bazaar. On the other hand also it is obvious that among these three regions meaning Jessore, Chittagong, Cox's bazaar, Cox's Bazaar has the lowest average wind speed but also with lowest UEC. So only considering the high wind speed sites for wind power generation system may not be economically fruitful.



*The Power deviation ratio is reduced by 80% from actual value

Figure 05: Comparison of annual average wind speed, power deviation ratios and UECs of seven different sites.

With a motivation to find a condition for selecting a site or region appropriate to construct a wind power generation system, a term named power deviation ratio is taken into account in this paper. In a particular site, wind speed may vary time to time causing variation in power generation which then varies the power deviation ratio with respect to the load of that site. An important relation between power deviation ratio and UEC of a particular site can be quoted from the Fig. 05 which is, with the increase in power deviation ratio of a site, UEC increases and vice-versa. Barisal has an average wind speed of 5.81 m/s and power deviation of this region is highest among other regions under consideration which is about 155.17% (actual value). But second highest power deviation of 141.37% occurs in Jessore where Jessore is said to have highest average wind speed. From Fig. 05, it can be seen that lower is the power deviation ratio of a site, the lower is the UEC. In our study Cox's Bazaar has the lowest power deviation ratio as well as lowest UEC and also has a good average wind speed and that is why this site is suitable to build a wind power generation station rather than Jessore, as Jessore has highest average wind speed, but it's power deviation ratio is also very high and also has high cost/kWh among the sites under consideration.

VI. CONCLUSION

This paper focused in figuring out the conditions appropriate for the selection of a site or region to setup a wind power generation system and also justifies the approach economically. For the selection of the site, as the high speed of wind is highly recommended, the power deviation ratio of the site needs to be equally evaluated to produce power at as much as low cost per kWh. This paper's prime findout is the relation of Power Deviation Ratio of a site with the Unite Electricity Cost (UEC) of that site. It is clear from the results and discussions that for a particular site, with the increase of power deviation ratio, UEC increases and with decrease in power deviation ratio, the UEC decreases.

Wind energy can be put to a variety of uses, especially for wind pumps, hybrid electricity generating systems with wind as one of the energy sources, small battery chargers at isolated places and electricity inputs to local grids in some coastal areas or the bay islands. To mention some practical applications, wind energy in Bangladesh could be used in shrimp production, fish or poultry firming, salt, ice production, fish-mill industries, hatcheries, domestic applications and vegetable irrigation - all using decentralized electricity. Wind energy is a clean renewable energy source cheaper to maintain, saves fuel and can give decentralized energy. We should make maximum use of it.

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