Integration of Renewable Energy Project: A Technical Proposal for Rural Electrification to Local Communities

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ABSTRACT The increasing environmental awareness across the globe is leading towards a green and clean world. Currently, Pakistan is going through an acute energy crisis; it is an on-going challenge for the government to provide uninterrupted power supply at economical rates to its citizens and potential industrial investors, now and in future. Thus, this energy scenario necessitates the incorporation of renewable energy technologies with power systems to enhance its generation capacity, and to overcome electricity outage of approximately 8-12 hours, in the country. In this paper, the authors encouraged the state policy for utilizing the wind energy for power generation, which is freely available across 1600 km long coastal belt of Pakistan. For this purpose, wind potential is explicitly evaluated across Sindh and Baluchistan provinces in Pakistan. The energy generated by various wind turbine prototypes is employed to suggest the most optimum location through optimal probability function. Moreover, this study provides an evocative progression based on real-time wind data to integrate wind power for rural electrification across the coastal zones of Pakistan. This study is expected to play an imperative role in incorporating wind farms on proposed sites to facilitate investors interested in investing in Pakistan’s energy sector.

INDEX TERMS Environmental challenges, wind power integration, Weibull/Rayleigh distribution technique, wind zone, rural electrification, renewable energy.

I. INTRODUCTION The increasing population and interest of investors to invest in various sectors across Pakistan has given rise to energy consumption. On the other hand, the country is significantly dependent on fossil fuels imported from various countries. The industrial, commercial and domestic sectors are extremely affected, and it is a big challenge for the Pakistan government to handle this power crisis in the near future. However, Pakistan is rich in conventional and non-conventional energy sources, and its effective use can boost the economy of the country. Primary energy resources in Pakistan are Nuclear, hydro, coal, wind, LPG, gas and oil.

Meanwhile, the per capita electricity consumption in the country is exponentially increasing. The government is introducing policy measures for increasing power generation infrastructure in order to keep pace with the increasing demand for electricity in the country [1]. The available installed power capacity is about 17 GW, whereas the demand is 22.5 GW, and averagely, the shortfall is approximately 5.5 GW. It is expected to rise to 8 GW till 2022 if the new energy sources will not be incorporated with the national grid system of Pakistan. Moreover, electricity demand and supply rates are facing an increase of up to 10 % and 7 % respectively. Correspondingly, it is also estimated that the power requirement in 2030 will be more than 45 GW. Whereas, in 2014 and 2015, the energy ingestion was 26.27 million tons of furnace oil in Pakistan that was 0.12 % less than the former...
year. The energy supply was increased by 4.9 percent that was 44.6 million TOE in the same year [2]. Among several energy subsectors, the energy consumption of natural gas and oil has increased by 7 percent and 3.7 percent respectively. The electricity generation has declined by 8.9 percent as compared to previous decade. From the years, 1990-2005, Pakistan went through an unexpected stage of copious electricity. However, after the short golden period, country is again facing the challenge to overcome the electricity shortfall. Since 2006, the supply-demand gap is continuously bourgeoning by each passing day but this gap has rapidly intensified to about 5.5 GW shortfalls, recently. In June 2015, electricity shortfall upsurge to about 6 GW. To reduce the demand-supply gap, load shedding was increased to 8-10 hours in urban and 18-20 hours in rural areas [3], [4]. The advantages of wind and solar electricity production, and considering the fact that these are most inexpensive and conveniently available forms for energy generation across the globe, is attracting the attention of the government energy policy makers [5]. It is estimated that in 2030, the planet will meet its required electricity demand from wind energy, as it is a clean renewable energy source available across all the countries and it possesses several environmental and economic benefits. For highlighting the efforts for the extension of wind power production in Pakistan [6], pecuniary growth has been arranged by the energy zone [7], [8]. However, the situation is worsening day by day and power disaster is affecting all the sectors badly. According to existing approximations, the energy shortage across Pakistan has cost up to 4GDP. Certainly, the progress in GDP and the energy utilization rate are primarily interconnected. Several factories and industries have been shut down due to the energy crisis. The energy crisis affected the economy of Pakistan badly. The power crisis originated almost five years back, and was a result of imported furnace oil. The reason for its origination was an extreme water crisis in several areas of Pakistan. It has enlarged the power generation cost because of the line losses that play a key role in increasing the tariffs and affected the power generation, power distribution and power transmission companies directly [9]. Pakistan has not prospered in accomplishing demand for energy by customary fuels and falls in the ten states of the world who has suffered from the energy shortfall. The existing distribution system lacks capability to carry over 15,000 MW. Subsequently, if the existing units may be producing three-fourth of their generating capabilities, even then the nation will not possess the required capacity for the distribution of such power for end-users due to outdated transmission systems [10]. Since the installed capacity of plants is greater than the real power generated, hence, the real power produced is not meeting the demand [11]. In this paper, global standards and interest for wind energy production are analytically considered. This study emphasizes on a comprehensive analysis of the two sites located in the coastal zone of Pakistan. These sites are considered suitable for the installation of multiple wind farms and producing electricity to meet the requirements of the people. Moreover, the analysis is validated through appropriate results at the heights of 10m, 30m, and 50m. An explicit study for wind assessment of the wind resource across the two proposed locations in the coastal zone of Pakistan gives a practical overview and understanding of two leading sites based on a comprehensive analysis and assessment technologies.

II. ENVIRONMENTAL CHALLENGES

Globally, numerous researchers are working on various renewable technologies and electric vehicles for providing a clean energy environment. In contrast to fossil fuel and nuclear technology-based power generation systems, wind turbines (WTs) do not affect the greenhouse gases and pose no risk to the environment. However, for the existing challenges authors have described the environmental challenge model as shown in Fig 1.

III. GLOBAL SCENARIO ON WIND ENERGY

In contrast to the existing works, this paper analyzes the expansions in the wind energy sector at a global level by focusing on the significant areas of the international market, technological issues in this field, environmental performance, economics, and the R & D scenarios of wind energy. The understanding of wind energy has escalated with distinct consideration in the European market. More specifically, the facts disclosed the contribution of European researchers across the global market. It is presented that the European market is leading the evolution of a global wind power generation and leading the market today. There are lot of technology issues, discussions on the machines up-gradation, and their control strategies which have attracted number of researchers. Several other issues include the commencement of the major technological characteristics of WTs issues, such as integration of grid, off-shore wind farms, the efficiency of the plant and the expansion of the small machines. Fig. 2 shows the increasing trend of installed wind energy capacity across the globe.

IV. WIND ENERGY DEVELOPMENT IN PAKISTAN

In Pakistan, the mechanism of wind power started with the protracted energy market. It has been initiated with the establishment of the first wind power plant in Iran during 500-900 AD. Pakistan has a salient ancient history that existed for the technology of wind energy. Recently, windy areas of mountains and about 1600 km extended boundary with the coast of Arabian Sea can be used for the installation of wind farms. The installation of wind farms across the deserted areas can also be considered to save valuable land for future use. It is also articulated that all the efforts started on a relatively larger scale in the 1980s to identify ways for taking advantage of wind power [13]. In the 1990s, two 10KWh and 1kWh wind turbine units were installed in Sindh respectively [14].

In March 2001, a report submitted to PCAT by Pakistan Meteorological Department, which for more than 50 years accompanied by cooperation on the basis of data has been
presented. The report of 2.10 m height on 50 stations in the country based on data record has been presented. It is expected 30 m wind speed and wind energy potential has been able to generate power. Another report shows the addition of areas of Sindh including Badin (Karachi) and Chor (Hyderabad) as these are the finest locations for the installation of wind energy. In 2001, the environment ministry has started a project with the support of United Nations and Global Environment Facility. Some development is started for wind energy technology to boost the international market and more investment in Pakistan. Moreover, CPEC is enticing numerous investors across the globe to invest over this new silk route. Correspondingly, Pasni along the Makran coast of Baluchistan is a global attraction for wind energy investors and the wind energy project feasibility for this region has been designed. Unfortunately, this project declined due to lack of motivation and wind energy data. Pakistan’s government has recommended a tariff policy to design a legal framework for the wind energy project in the future [15], [16]. Moreover, fourteen small wind turbines were purchased by government of Pakistan, from China, out of which eight wind turbines were installed at the Baluchistan coastline; and remaining six wind turbines are proposed for the coastline of Sindh province. However, small wind turbines selected for installation at the coastal line for rural electrification purposes [17], [18].

In 2004, a foreign company completed a wind-diesel hybrid system successfully for the rural electrification in a village of Sibi, in Baluchistan [19], [20]. Another study completed during 2004-2007 that has been determining wind data
at twenty different sites in the coastal area of Sindh province [21], [22]. In accordance to the international standards, four sites near Indus river, i.e., Jamshoro, Nooriabad, Talhar and Kati-Bander are found as optimum locations, and other four sites over the coastal belt of Sind Province, i.e., Thano Bola Khan, Hyderabad, Gharo, and Thatta were examined the best locations for installation of wind turbines for power generation [23], [24]. Alternative energy development council act, 2011, signed between AEDB and govt. of Pakistan, supports the land used, evaluation of projects and renewable energy plans and policies for adoption for incorporation of renewable energy across Pakistan. Govt. of Pakistan is also interacting with national and international organizations to support renewable energy projects, as directed by AEDB [15], [25], [26]. The aforementioned policy of 2011 was unconcerned to alternative and renewable energy of policies in 2006. This law supports to provide the 346 GW wind power potential, of which about 60-70 GW is technically utilizable for power plants [27]. The aim of the Government for the wind and solar energy sources is to add the fifty percent mix energy to the national grid. In contrast, it is a well-established growing industry in China, with around 1.5 billion populations in a country that is 19.24% of the world’s total population [28]–[30]. In 2010, China’s 4716 TWh production exceeded the USA with 4208 TWh in the world largest power producer. The Energy information administration (EIA) report states that total energy production of China was about 5126 TWh in 2013. China has a good financial system and GDP of 7% or more of the fast growth year. China is using about 10.7 million barrels of oil every year being the 2nd largest oil consumer. China and India are in the competition for being an advanced country. Energy resources are exploited for cost-effective development of a nation and renewable resources can be improved due to contribution growth of GDP in ecological anxiety point of view [31], [32]. Figs. 2–4 show wind data measurement station with sophisticated mapping scheme for Geographical Information System (GIS) to indicate the region. Wind potential resource 132 GW is available in Pakistan and more focused in the study.

### V. WIND RESOURCE OVERVIEW

One of the finest reports studied till date was issued by NREL and U.S. Agency for international development (USAID) assistance program in 2015 as shown in Fig. 3 (a). In this report, mesoscale map of Pakistan is discussed. The potential of wind speed at a height of 50m is illustrated in Fig. 3 (b). Several suitable locations for the installation of wind turbines and energy generation are discussed in this report where central areas of KPK, north western locations in Balochistan are discussed with the southern part of Sind province in Pakistan. Moreover, some isolated corridors in Pakistan, like central and southern Balochistan, central and western Punjab along with remote areas of Gilgit Baltistan are elaborated in this report. By using the numerical modeling technique in Geospatial Toolkit (GST) annual wind power high resolution (About 1km) maps have been developed for the USAID program by NERL. In order to assess the wind resources of Pakistan, these high resolution maps and the other reports [26], [33]–[38], are found quite significant.

Wind potential survey in Pakistan is also carried out by the Pakistan Meteorological department (PMD); PMD has observed the data for fourteen sites of Pakistan in northern parts, including Federally Administered Tribal Areas (FATA). The average speed and direction of wind were observed for approximately ten minutes at 10 m and 30 m heights. PMD has observed similar data in coastal areas of Balochistan and also on twenty different sites in coastal areas of Sindh forecasted that ranges around 40-70 % wind potential (See [38], [39]).

### VI. WIND ENERGY POTENTIAL

By using GST [40], the assessment of wind resources was done by NREL. While calculating this, the land area of a country is kept under observation, the over-all area of Pakistan is 796,996 Km², while the total land area without water area is 770, 875 Km². The estimated wind power potential for entire area reveals that a 5MW of wind turbines can be installed at a per square kilometer [5], [41]–[43]. Table I illustrates the assessment of wind power potential.

It is evident from Table 1 that almost 9 % of the total land is highly suitable for the installation of wind turbines in Pakistan. Therefore, it shows that over 349,000 MGW wind power potential can be generated via installation of wind turbine units. For cost-effective wind turbine units, class 4 or greater wind speed is needed, which is available in 3.5 % of the area [41]–[46]. Total wind capacity via this 3.5 % of land is 132,990 MW. In [47], [48], it is described that the total energy requirement of Pakistan is 16,500 MW, and this power production capacity from the wind is highly considerable. The need of the hour is to efficiently exploit this wonderful wind power potential. AEDB has been commended for its

| Power Class Chronicles | 3 | 4 | 5 | 6 | 7 | Total |
|------------------------|---|---|---|---|---|------|
| Windy area (km²)       | 43,265 | 18,219 | 5320 | 2514 | 545 | 69,863 |
| Accumulative Windy area (%) | 5.61 | 2.36 | 2514 | 0.33 | 0.07 | 9.06 |
| Installation Capacity (MW) | 216,325 | 0.69 | 26,600 | 0.07 | 2725 | 349,315 |
obligation to develop a substantial wind potential, and it has taken some steps for its development. The potential areas are southeastern Sindh, followed by northwestern Khyber Pakhtoon-Khuwah and southwestern parts of Balochistan. Table 2 describes the total power generation capability and percentage of total wind area for each province by using thumb rule i.e. $1 \, \text{km}^2 = 5 \, \text{MW}$.

VII. WIND POWER CLASSES
Wind power is categorized in different classes, the most suitable class is class 3 for the installation of the wind turbine and class 2 is used in rural applications. $10 \, \text{m}$ and $50 \, \text{m}$ height along with their parameters of the classes of wind power categories, listed in Table 3. WTs with the hub-height of $50 \, \text{m}$ are medium size, commercially available turbines mostly used in the field to produce power. WTs setups at the height of $50 \, \text{m}$ is extrapolated in filed to generate perforable power for company. WTs respond positively to speed more than $5.5 \, \text{m/s}$ due to the economical production of wind power. To meet the prerequisite of a profitable wind power production is used in the wind power classes as shown in Table 3. The government of Pakistan has performed wind resource
VIII. MATHEMATICAL MODELING

In the existing literature, the data of wind speed is outlined, together with variances and average histograms. The summarized facts are disseminated by frequency distribution, Rayleigh and Weibull distribution for wind speed deviations. Wind energy generation is conditional to the wind speed and time fraction for which this wind speed is available. Moreover, air density, height and design of wind turbine are important factors that affect the production of electrical energy. All these factors are explained in detail in the following sections.

IX. WIND SPEED MODEL

Wind speed variation model is defined as follows:

$$\frac{u(Z)}{u_r} = \frac{\ln(Z/Z_o)}{\ln(Z_r/Z_o)}$$  (1)

where, \(u(Z)\) represents the height of wind speed \((Z)\), and the reference wind speed \(u_r\) at reference height \(Z_r\), length of
Weibull constraints use the wind speed data maximum likely distribution, various procedures are described in the literature. To fit the measured data of Weibull distribution, that are alternate function used to determine wind speed. To fit the measured data of Weibull distribution, that are alternate function used to determine wind speed. Moreover, Weibull probability density is generally used to exemplify the wind speed distribution specified in (2)

\[ p(u) = \left( \frac{k}{C} \right) \left( \frac{u}{C} \right)^{k-1} \exp \left[ -\left( \frac{u}{C} \right)^k \right] \]  

where, \( k \) symbolizes the shape factor. The large value of \( k \) illustrates the sharp peaked curve and \( k \) describes the scale factor. \( k=2 \) lessen the Rayleigh distribution and \( k=1 \) shows data of wind speed variation and thus overestimating easily energy features of the power, which does not take into account the economic feasibility. It is a much more expedient to the economic feasibility. It is a more expedient for finding the wind speed across Badin and Pasni, Pakistan. Table 3 displays the different heights along with wind speed and average density of wind power.

### INTERNATIONAL WIND POWER CLASSES STANDARD

| Wind power class | Height | Poor    | Marginal | Moderate | Good   | V. Good | Excellent | V. Excellent |
|------------------|--------|---------|----------|----------|--------|---------|-----------|--------------|
| Characteristic   |        |         |          |          |        |         |           |              |
| WPD (W/m²)       | 10 m   | 0-100   | 100-150  | 150-200  | 200-250| 250-300 | 300-400   | 4400         |
| Speed (m/s)      |        | 0-4.4   | 4.4-5.1  | 5.1-5.6  | 5.6-6.0| 6.0-6.4 | 6.4-7.0   | 47.0         |
| WPD (W/m²)       | 30 m   | 0-160   | 160-240  | 240-320  | 320-400| 400-480 | 480-660   | 1600         |
| Speed (m/s)      |        | 0-5.1   | 5.1-5.9  | 5.9-6.5  | 6.5-7.0| 7.0-7.4 | 7.4-8.2   | 11           |
| WPD (W/m²)       | 50 m   | 0-200   | 200-300  | 300-400  | 400-500| 500-600 | 600-800   | 4800         |
| Speed (m/s)      |        | 0-5.4   | 5.4-6.2  | 6.2-6.9  | 6.9-7.4| 7.4-7.8 | 7.8-8.6   | 48.6         |

Average power density in one year is premeditated at the height of 50m that is nearly 414 W/m² in Badin and Pasni. Energy density is measured as 3267 kWh/m² for the rotor area. The power curve of wind turbine and wind speed helps to find average power by using the following relation in Eq. (6):

\[ P_W = \frac{1}{n} \sum_{j=1}^{n} P_W(u_j) \]  

Moreover, the over-all output power is assimilated multiplication of number of time intervals in hours. Total power generation will be calculated by using bin wind velocity information. Following relation in Eq. (7) is used for power calculation.

\[ P_W = \frac{1}{n} \sum_{j=1}^{n} P_W(m_j) N_j \]  

where \( N_j \) represents the number of cycles in \( j^{th} \) bin, \( m_j \) and \( n_b \) are the midpoint of the totality of box.

### XI. ELECTRICITY GENERATION MODEL

Average output power of wind energy conversion technologies (WECT) is a significant as it sets standard power yield in excess of the instance and so the effect on wind energy project due to the economic feasibility. It is a much more expedient feature of the power, which does not take into account the wind speed variation and thus overestimating easily energy revenues. \( P_{WT} \) is the Wind turbine power generated at respective wind speed can be articulated as:

\[ P_{WT} = \int_0^\infty P_{WT}(v) df(v) \]  

\[ P_{WT} = \sum_{j=1}^{n_b} \left\{ \exp \left[ -\frac{(u_j-1)^k}{C} \right] - \exp \left[ -\frac{(u_j)^k}{C} \right] \right\} \times P_{WT} \left( \frac{u_j-1 + u_j}{2} \right) \]  

Accessible power at a certain wind speed ‘v’ which is alterable by a turbine can be calculated by Eq (10).

\[ P_{WT} = \frac{1}{2} \rho AC_p \eta u^3 \]  

Table 3.
To interpretation for the aforementioned restraints can be verbalize a new formula for average electrical power production of a wind turbine and it is calculated by Eq (11).

\[
P_{WT} = \begin{cases} 
\sum_{j=1}^{n} \left\{ \exp \left[ - \left( \frac{u_{j-1}}{C} \right)^k \right] \frac{P_{WT}}{u_{j-1} + u_j} \right\} \\
- \exp \left[ - \left( \frac{u_{j-1}}{C} \right)^k \right] P_{WT}(u_r) \\
0 
\end{cases}
\times \left( \begin{array}{c}
\frac{u_c}{u_s} \leq u \leq u_r \\
\frac{u_r}{u_s} \leq u \leq u_f \\
v < v_c \text{ and } adv > v_f
\end{array} \right)
\]  

(11)

The actual energy output is divided by conjectural maximum energy output during a selected time span, RO (t) given in (12).

\[
CF = \frac{P_{WT}}{RO} 
\]  

(12)

The capacity factor varies from 0-100 percent but practically fluctuates from 20-70 % and typically be around 20 to 30 %. Wind turbine viability is not dependent upon the capacity factor but also depends upon the cost of substitute power systems. Turbine prices are evaluated by using the thumb rule [49]–[51] of US $ 1000 kWh, like $ 450,000. The entire method of price is taken as 20 percent of the turbine rate whereas preservation and procedure as 2 percent of total turbine costs per year. The total life of 20 years and 5 percent of interest rate, electricity unit rate is determined as 3.6 pennies for 1 kWh. These inclusive economic benefits and recommended size analysis endorses that an off-grid wind power generation is liable to be considered censoriously for neighborhood groups. Turbines are frequently designed for commercial use especially for the spots at high wind speed and do not affect much at low wind speeds. Numerous turbines are made to yield advantage of local wind systems that subsequently lessen the price. Local production of turbines brings down the bills greatly.

### XII. RESULTS AND DISCUSSION

The American wind power chart comprises of seven wind energy production methods, that signifies, wind power as an appreciated asset of energy generation at site, initiated from first smallest to seventh greatest energy. The standard power density of nearly 414 W/m² at 50 m height sideways with 7.16 m/s average wind speed of per year, categorizes Pasni and Badin in class 4 that is the furthermost appropriate class for the application of wind turbine altering from small turbines and stand-alone to grand turbine units and large wind farms. Additionally, the bigger wind farm demands plenty of inspection expenses that will be an extra expense while a valuation of a stand-alone system for limited domestic use is provided. There are many advantages of a small off grid power generation system or small-grid founded on renewable energy system. It is obvious in some cases that the main-grids are inextensible to remote locations or areas far away from main urban cities. So far, the accessibility of electricity from the grid, it is reasonable to practice only as a backup, i.e. during the low-wind season. At Pasni and Badin, the wind speed is reasonably higher during the summer, when gigantic electricity is there in urban areas for cooling load. By selling additional electricity to the grid, it becomes more suitable to produce a decent turn over. The total population of Badin is around 29000 who use power at the countrywide cost of 424kWh per year, the total requirement of energy consumption is 1230 MWh. Moreover, by selecting a 150kW and N27/150 rating wind turbine, with a diameter of 27 m and by placing it in the middle of 30 m rather than 50m height, absolute for calculation and assessment purpose, as displayed in Table 4. By using wind speed of 30 m, the energy generation can be calculated as 475MWh each year. Suppose the following three turbines are employed in the system.

### XIII. POWER GENERATION WITH VARIOUS WINDTURBINES

A wind turbine operates on a particular site according to the design parameters, cut-in wind speed, cut-out wind speed and rated power are selected according to the location of wind characteristics. Wind turbine efficiency is not dependent upon the characteristics of wind site but on wind speed distribution.
TABLE 5. Per annum electricity generation through various wind turbines.

| WT Model     | Power (MW) | Energy (GWh) | Capacity Factor |
|--------------|------------|--------------|----------------|
| Nordex 90/2300 | 0.831      | 7.218        | 0.36           |
| Nordex 77/1500 | 0.560      | 4.860        | 0.37           |
| Nordex 27/150  | 0.071      | 0.618        | 0.47           |
| Bonus 2300/82.4 | 1.058      | 9.272        | 0.46           |
| Bonus 1300/62  | 0.512      | 4.50         | 0.72           |
| Bonus 1 MW/54  | 0.353      | 3.094        | 0.35           |
| Vestas V80    | 0.928      | 8.127        | 0.46           |
| Vestas V63    | 0.479      | 4.192        | 0.32           |
| GE45.7        | 1.281      | 11.220       | 0.56           |
| GE/1.5SL      | 0.789      | 6.909        | 0.53           |

[49], [52]. It is found that the maximum efficiency of a wind turbine is 59%. The range of wind turbine rating is 300 kW (Bonus300/33) to 2500 kW (Nordex N-80/2500). Wind generator extracts higher power from the wind to use of the wind turbine parameters such as cut-in wind speed, cut-out wind speed and hub height are given in Table 4. The data of wind speed is measured at the 30 m height to be considered in this study. Using power law expression for wind speed at different hub heights are calculated. The annual wind turbine power generation and capacity factor of plant are shown in Table 5. Vestas V42/600 wind turbine has minimum capacity factor value 0.28, and GE45.7 wind turbine has a maximum capacity factor value 0.56. GE45.7 Maximum energy produced by wind turbine is almost 11220.32 MWh. Vestas V42/600 wind turbine energy produces minimum 770 MWh annually. The capacity factor and annual energy production of wind turbines are depicted in Table 5. Finally, wind potential is investigated, and the site is analyzed to provide a potential path for the investors to choose wind turbine for their projects.

XIV. ENERGY DENSITY AND WIND POWER

Wind speed and power density are illustrated in Fig. 4 (a) and Fig. 4 (b) respectively. In summer specifically from May to August wind power density is highest as shown in Fig. 4 (b). Provided wind data at the candidate sites of Pasni and Badin are compared with power densities computed via Rayleigh and Weibull functions of wind power density.

Three power densities are compared by monthly variations of wind data of the Badin and Pasni. The actual data based on the highest wind power density occur in August 2006 value 717.661 W/m². The whole survey completed in June 2012-July 2015 with the specific values of the wind data 694.774 W/m² and 674.774 W/m² respectively. Wind power density values 30.506 W/m² is a lowest period which occur in November 2015.

The comparison of observed wind data with Rayleigh's function and Weibull's function was done on a monthly basis and observed thoroughly. Though the lowest value of WPD is 30.506 W/m² which occur in Nov 2015, during the months of October to December every year, the lower wind power densities are mostly observed. The highest wind power density, based on actual data, occurs in Aug 2015 having value 717.661 W/m² succeeded by Jun 2012, Jul 2013-Jun 2014 with 693.566 W/m², 674.774 W/m² and 671.612 W/m² correspondingly. Similarly, the average energy density values for Pasni and Badin are high during the months from May-August. It is noticed that the energy density has the highest value in June for 10m and 50m heights, whereas, the value of energy density is highest for the month of July if the 30 m height is considered, as shown in Fig. 4 (b). The maximum and minimum values for wind data by considering the measured figures of five years were found 533.940 kWh/m² in the month of August, 2004 and 22.061 kWh/m² for the month of Nov, 2006 respectively. The Capacity factor and estimated power generation at the proposed site located in Badin are demonstrated in Fig. 5. It is noticed that the maximum estimated power generation is required in June. It is due to hot weather and escalating temperature. Likewise, wind speed distribution at the proposed Pasni site is shown in Fig. 6. The results computed for percentage frequency distribution and probable Weibull distribution for the proposed Pasni site at three different heights are shown in Fig. 6.

It is observed from Fig. 7 that wind power density remained maximum in the sixth month of the year for proposed Pasni site. Moreover, the analysis for the capacity factor and the estimated power generation is also conducted thoroughly and depicted in Figs. 8 and 9 respectively. The analysis validates that the proposed sites are highly suitable for wind farms incorporation. This study has proven very helpful for the investors as well as for the government of Pakistan to install the renewable energy sources at the proposed sites to generate energy in order to overcome the ongoing energy crisis across Pakistan.

XV. SEASONAL VARIATIONS

The wind data for three years i.e. from January 2005 to December 2007 has been analyzed comprehensively to determine the average wind speed with respect to summer, autumn, winter and spring seasons. For this purpose, May-July are considered as summer, Aug-Oct is autumn, Nov-Jan. is winter whereas the spring starts from Feb ends in April. The average
wind speed determined after the analysis for all the four seasons is 7.63 m/s, 5.63 m/s, 3.61 m/s and 4.71 m/s for summer, autumn, winter and spring seasons, respectively. The wind speed variation shows that the speed of wind is comparatively high during summer, followed by autumn, spring and winter. The shape parameters along with Weibull scale
Variations in power density and energy density due to seasonal changes are shown in Fig. 10 and Fig. 11. Power density and energy density are higher on investigated site in summer season followed by the winter season. The highest value exists for wind power density is 565.586 W/m² in summer and lowest was 83.576 W/m² in winter 2005. Comparison of wind power density measured through calculated wind data from Weibull scale and Rayleigh’s function is also depicted comprehensively for Badin site as shown in Fig. 12. However, the results for Pasni site are depicting that power density and energy density are relatively higher for summer and autumn seasons as demonstrated in Figs. 13 and 14. Correspondingly, Comparison of wind power density measured through calculated wind data from Weibull scale and Rayleigh’s function is also depicted comprehensively for Pasni site as shown in Fig. 15.

**XVI. RECENT DEVELOPMENTS IN WIND ENERGY SECTOR**

The AEDB is issued by the license to 34 independent wind energy companies for investment in 1925.4 MW wind powers. After the issuance of a letter of intent, the land is allocated to be used by company managed staff for better improvement in projects. AEDB has issued supportive letters to the company to develop the project successfully and to hire technical experts based on demand of the company. This is followed by obtaining a generation license and determining the tariff by NEPRA, signing of the power purchase agreement by NTDC and agreement signs with AEDB Company. The commercial operation of the wind power plant has achieved financial closure. It was issued by letter of support to 15 independent wind power producers which amount to commercial operations achieved of 806.4 MW wind energies of projects. Wind power producer’s details and their different projects are as follows:

**A. FAUJI FERTILIZER COMPANY (FFC) PROJECT**

FFC Energy Ltd.’s wind power plant, situated in Jhimpir, occupies approximately 1283 acres of land in Sindh. Wind power plant installed capacity is 4.9 MW with generation from wind 146 GW per year. NEPRA has regulated tariff rate of 16.109 cents/kW h for FFC Energy Ltd [52]–[54]. It has completed 50 megawatt wind farm in record time by FFC Energy Limited (FFCEL), a subsidiary of FFC well-known by a dream to commence and encourage renewable energy and environmentally friendly plants in Pakistan.

**B. ZORLU PROJECT**

Zorlu Energy Company was situated in District Thatta Sindh province in Pakistan. Turkish firm Zorlu Enerji subsidiary. On this project the investment was 143 $ US Dollar. In the
F.Y 2009, a 6 MW capacities and each wind turbine, 1.2 MW vestas, were installed. Later, 28 VestaS, 1.8 MW turbines have been installed that accumulatively increased the capacity of wind farm around 50.4 MW. NEPRA has regulated the tariff of 13.3456 US cents/kWh for the wind power plant installed by Zorlu company in partisan. In April 2013, the project was expected to be finished [39].

C. THREE GORGES FIRST WIND FARM PAKISTAN
The Chinese company established a wind power plant, situated in Jhimpir, Sindh. It spent 130 $ US to establish 49.5 MW wind power scheme in recent times started on April 11, 2015. 33 turbines of Gold winds GW771500 were utilized in Pakistan. Intention to increase the capacity of wind power plant 500 MW has been accounted [6]. NEPRA has regulated a tariff rate of 13.9399 cents/kWh for this wind scheme. The time frame of these IPPs (see Table 2). The project started for power generation and it was achieved approximately 93 million kWh.

D. FOUNDATION PROJECT I AND II
Two projects 50 WM each, which are in progress situated at KuttiKun new Island, Sindh. FWEL-I requires a land area of 1210 acres and FWEL-II required a land area of 1656 acres.
The total expenditure prescribed for FWEL-I is approximately 128$ million US dollar for FWEL-II the expenditure is approximately 127$ million US dollar with a debt equal ratio of 75%:25%. NEPRA regulated tariff 14.1359 cents/kWh for FWEL-I and 14.1164 cents/kWh for FWEL-II.

E. SAPPHIRE PROJECT

This project is going to produce wind power of 50 MW, situated on 1372 acres in Jhimpir, Sindh. Recently, 33 latest wind turbines are being installed by General Electric. The project is granted by Bank Alfalah and Sapphire Textile Mills Limited. The financial assistance is accomplished through Overseas Private Investment Corporation (OPIC). The main contractor for this project is Hydro-China Corporation. The agreement is signed in September 2013 with OPIC and Sapphire Wind Power Limited. The Company has agreed for a system of tariff in advance with the Government.

F. YUNUS PROJECT

Yunus energy project is the power production group of Younis brothers and was started in 2011. Their wind power project is situated in Jhimpir, Sindh having an installed capacity of 50 MW. In December 2011, Pakistan has issued support letter to the company for wind power generation. In November 2013, the tariff is permitted by the NEPRA when accepted with the corporation. The corporation signs a power purchasing consistency with the central power purchasing authority NTDC on 26th March 2014. The company is facing 210 million rupees’ higher revenue along with unpredictable exchange rate and a rise in extra inconsistent expenses is declared. In situation project did not achieve financial closure.

G. SACHAL PROJECT

Sachal Energy Development Limited is a subsidiary of Arif Habib Corporation Limited. In 2012, Sachal Energy has constructed a 49.5 MW wind power project in Jhimpir, Sindh. A Chinese Company, Hydro China Limited was employed for engineering, development, operation and maintenance services in April 2012. Winds farm construction cost is around 107$ million, and it will be provided by Industrial and Commercial Bank of China. It is estimated that, the annual capacity of power plant will be 136,500 MWh and reduce emissions of greenhouse gasses 85,000 tons per year.
**H. METRO PROJECT**

Metro project has installed a 50 MW project of wind power near Hyderabad, Sindh. In February 2015, this scheme has accomplished a financial closure; in August 2016, it is predicted to start the production; NEPRA declared a14.4236 cents/kWh tariff rate for this scheme in May 2012; 1553 acres’ land is allotted for this wind power plant.

**I. GUL AHMED PROJECT**

Gul Ahmed project is a 55% owned subsidiary of Gul Ahmed Energy Limited. As well as Infraco Asia owns to GAWPL, International Finance Corporation of the wind power project is a minority shareholder. In December 2011, Company has obtained the permit of production. The Scheme of Metro Power Company Ltd, near to its group companies, installed a power project. GAWPL has installed 50 MW Nordex turbines in wind power projects. A wind power project requires 645 acres. The corporation has preferred 13.5244 cents/kWh tariff rates.

**J. TENAGA GENERASI PROJECT**

A 50-megawatt wind power plant is installed by the company in Gharo, Sindh at an estimated cost of 130$ million US Dollar. The project covers an area of 4881 acres. The schemes are probable to generate electricity 156 GW h at 36% capacity factor average of per year. The company obtained LOS from AEDB in September 2010 and has selected for the upfront tariff.

**K. MASTER ENERGY PROJECT**

Master Wind Energy Limited is a subsidiary of Master Group. The company has obtained a support letter from the Asian Development Bank, to construct 50-megawatt wind farm near Jhimpir’s. Moreover, every organization required a licences for power generation plant, therefore this got it from the NEPRA and has determined by the tariff under the tariff management system. The tentative rate of this scheme is 125 $ million US Dollar. The company obtained LOS on August 08, 2012; On March 20, 2015, NTDC Limited signed an agreement with the master group to purchase power; in 2015 financial closure was completed by the corporation and in September 2016 operation began.

**L. ZEPHYR PROJECT**

Wind data analysis in Pakistan Zephyr Power Limited is a sister company of Omega Limited been done. In January, support letter is acquired from AEDB; the wind farm is constructed near Bhambore, Sindh. In May 2012, NEPRA has regulated the 15.9135 US cents/kWh tariff rate for Zephyr Power Limited. The company has installed 33 Sinovel wind turbines and total capacity of 49.5 MW wind farm are installed in Bhambore.

**XVII. RENEWABLE ENERGY PROJECTS REQUIREMENT**

The government of Pakistan has major focus on liquefied natural gas (LNG) based power plants, solar and wind energy project impracticable professed by the Pakistan government for comparatively high cost as compared to conventional power generation projects. Even some projects were issued and signed for their integration in power production in Pakistan; however new proposals are accepted currently from the government and serious measures are taken for development of Wind turbines. The renewable energy market in Pakistan is affected till now by new guidelines of the government of Pakistan.

As a substitute of interdiction new suggestions, it must change dogmata to encourage IPPs to generate cheap power. Some recommendations are as follows:

- In order to maximize the benefits of participation, for using better techniques of risk management, corresponding risk in multi-product market environment should be reduced.
- The indicators should be used for the better understanding of intermittence and wind power uncertainty in different locations
- Hydro and thermal power stations should be improved by the accessible development.
XVIII. PAKISTAN POWER POLICY
Government of Pakistan’s Ministry of Water and Power had to design a power policy due to severe energy crisis in the country. The ambitious power policy 2013 was framed in such a way that it can meet Pakistan’s present and future energy requirements. The aim of this policy was not only to address the main challenges which are faced by power sector but also to tackle the problems of economy and social development. Better living standard and relief was one of the main resolves to be provided to citizens of Pakistan via this strategy.

A. GOALS
Government of Pakistan has set nine goals with the aim of achieving long-term solution for power sector problems and challenges which are given as follows:

- Improve power generation efficiency according to world class standards.
- Diminish financial losses throughout the system.
- Create an out-class network for transmission.
- Construct a sustainably sound power generation capacity to meet Pakistan’s energy needs.
- Guarantee the power generation of affordable and inexpensive electricity by using indigenous reserves like Hydel and coal (Thar coal) for industrial, commercial and domestic use.
- Make the fuel supply free of pilferage and adulteration.
- Create a practice of conserving energy and responsibility.
- Improve the governance of all provincial, federal departments and align the ministries related to energy sector. An effective and long-term vision policy has to be made for each goal mentioned above to actualize the power sector’s aspirations.
- Improve the distribution system and minimize the inefficiencies.

B. POLICY PRINCIPLES
- Power policy 2013 consists of the policies and strategies based on the following organizing principles:
  - Sustainability
  - Efficiency
  - Competition

1) SUSTAINABILITY
The ground factor for long term transformation is based on Sustainability. It consists of three pillars: demand management, low cost energy and fair playing field. Less expensive fuels can be used to achieve the target of low-cost energy. To attain sufficient investments for low cost fuel mix, electricity tariff rationalization was necessary. To achieve equality in the system, practice of cross-subsidizing the consumption of rich should be ended as well as rights of poor must be protected. All industrial consumers can be provided with power at equivalent price which will create a level playing field in the system. The demand management will be introduced through regulatory instruments, pricing and novel policy.

2) EFFICIENCY
Efficiency plays the most important role for excellence in the economic race and competition among nations at present times. Three main pillars are set by national power policy to determine the principle of efficiency: accountability, merit order and transparency/automation. To assess the merit order throughout the system, a policy was designed. Power mix, dispatch, payments and fuel allocation were observed through this policy. The merit order allocations will definitely come into play, once the demand and supply gaps have been minimized. To make the system successful, transparency is a necessary factor; it can be attained by providing complete access to information via public forum; Accountability system should be opted and implemented through competent professionals; Zero tolerance policy should be exercised towards poor performance and corruption.

3) COMPETITION
To develop a robust energy cluster, competition plays the most essential part. Principles of competition were based on three factors: key client management, infrastructure development, and competitive bidding as well as up front tariff. The infrastructure was improved and incentives were provided to attract private sector investments. It was planned that role of government will be limited to framing policies and making decision. Services’ delivery was to be encouraged through transparent and competitive private sector. Hence, NEPRA has to be supported and strengthened for the formulation of world class regulatory authority which can establish tariffs and lay down the foundation for a world class competitive bidding process. The government has to assign its representative for Ministry of Water and Power who will work as relationship managers or key client managers. Government representatives had to ensure the completion of investments and projects in time for power sector investors [33].

C. IMPACT
This policy’s success mainly depended on its implementation; it was expected that with the application of all policy principles, power sector will improve tremendously. According to prediction, this policy will have a great impact and demand supply gap would be eliminated completely and country would have an enough power supply than the requirement and can be traded regionally too by the end of the five-year term of then government. If this policy was implemented effectively, it was expected that Pakistan will resolve its power crisis and will transform itself from a power importer to regional power exporter. Power generation cost would be decreased reasonably and with efficient improvements in transmission and distribution, the burden of overload of power to end consumer would be significantly reduced. Power policy 2013 was designed to achieve social development and prosperity in Pakistan. But the bitter reality is that, with continuous instability and changes in political scenarios, actions and implementation of this policy is still not achieved.
XX. WHY RENEWABLE ENERGY SOURCES

Following are the points that demonstrates benefits provided by renewable energy systems:

A. ABUNDANT SUPPLY

The renewable energy is extracted from natural resources which are abundantly available. Therefore, they can supply ample power in the system. Additionally, recycling facility is available in natural resources so these are available through recycling process as well.

B. SUSTAINABLE

These energy resources are significantly sustainable; an optimistic feature of a natural energy source is that it supplies the required power while avoiding its harmful effects on the environment.

C. ENVIRONMENT FRIENDLY

The renewable energy is produced either by natural source or by altering a natural material into energy that ensures the environmental sustainability, hence, it is considered environment friendly. Consequently, there is minimal damage to the atmosphere due to it. Mostly locally available and needs no networking

Local availability of these resources is another key benefit of these resources. These are free of bearing the load of wide networking to use these resources at large or individual levels.

XXI. RENEWABLE ENERGY POTENTIAL

The energy shortfall problem of Pakistan can be effectively resolved by exploitation of the natural energy resources; moreover, it can provide a long term and feasible solution for abolition of many prevalent energy-issues of the country. The potential of these resources in Pakistan have been discussed exclusively in the subsection of this paper. Following text outlines an overview of availability of these resources in Pakistan:

A. HYDROPOWER

Pakistan has a wide-range of about 51,700 Mega-Watt in hydro power sector that comprises of a large Hydro Source MoW&P and PPIB.

B. SOLAR PV

The solar power potential is immense in Pakistan as it obtains an inordinate deal of solar-radiation that provides a considerable power generation facility. In Pakistan, on average a solar irradiation is 5 to 7 kWh/m²/day that is among the largest figures of solar irradiation arrive through the globe. Pakistan can harvest over a 1 million Mega-Watt of PV Solar electricity providing a possible installation space.

C. SOLAR THERMAL

As specified in the previous sub-section, Pakistan receives 5 to 7 kW/m²/day solar irradiation, through which thousands of Mega-Watt can be produced by using Thermal-Solar Power generation. Even though the precise production figure is not documented, it would be adequate to fulfill the energy in shortfall of Pakistan. Moreover, this much strong irradiation is useful for small-scale applications i.e. in domestic and commercial solar water heaters.

D. WIND POWER

The overall wind energy potential in Pakistan is more than 300,000 Mega-Watt that would effectively cater to the burning issue of electricity shortfall of country.

E. BIOGAS

The economy of Pakistan is dependent upon agriculture that provides a huge amount of livestock. Thus, there is a huge latent of energy production by means of biogas. The projected potential would be 8.8-17.2 bn m³ that would be helpful to generate 55-106 TWh of electricity. Thus, around 6.6% (5700 GW h) of Pakistan’s existing power generation capacity can be generated from biogas.

XXII. BARRIERS IN RENEWABLE ENERGY PROJECTS

As Pakistan is facing a one of the worst energy crisis of its history, notwithstanding the point that Pakistan is in ominous requirement of all available actions to be taken to resolve the energy generation deficit. Unfortunately, various factors hinder the improvement of long-standing issue. Subsequent
are the barricades confronted by organization working for the implementation of their renewable energy projects:

**A. POLICY CHALLENGES**
Currently, the government is not concerned with making amendments in the policies for renewable power generation sector. The foremost recognition should be specified to these energy sources and the financial inducements e.g. long-term licenses (as time consuming and long licensing procedures are there), feed-in-tariff, elimination of external costs must be removed on non-renewable energy sources, etc. It is a big hurdle from receiving the assistances from these renewable resources [39].

**B. POOR INFRASTRUCTURE AND MARKET ACCESS**
Extraction of energy from renewable energy source requires grid reinforcement, adequate grid codes and related infrastructure. This means that a huge amount of investment is required for power infrastructure allowing RES into the national grid.

**C. INSTITUTIONAL BARRIER**
Main departments concerned with energy sector, display a non-appearance of direction associated to the expansion and growth of investment in the sector of renewable energy generation. There is lack of co-operation among relevant agencies of government of Pakistan (AEDB, NEPRA, MoW&P, MoP & NRS etc.) which hinders the utilization of these resources.

**D. INFORMATION BASE AND TECHNICAL CAPACITY**
Deficit of methodological material and information among public is also another main barricade in the harvesting of renewable energy generation i.e. sunshine data and wind speed data that is obligatory to guarantee the benefits of these resources. The shortage of expertise (e.g. contractors, suppliers of equipment) and service providing companies (consultants etc.) is another big hurdle in this field. The prescribed projects are obligatory for the sustained operation of renewable energy generation technologies [6].

**E. FINANCIAL BARRIER AND LACK OF INVESTORS’ CONFIDENCE**
Finances are always considered a biggest hurdle in this sector. It is a significant factor in the slow expansion of energy sector. The exertions to use renewable energy are stalled due to insufficient capitals and financial enticement schemes. The current security situation and political issues also play its part to pose the growth in power sector as it is a risk factor that stops the local and international investors and they vacillate in capitalizing in the field.

**F. LACK OF SOCIAL AWARENESS**
Further, one key difficulty in the growth of renewable energy production in Pakistan is the lack of knowledge and awareness about the compensations attained through renewable energy and it plays a very important role.

**XXIII. CONCLUDING REMARKS**
The main purpose in this research work is to analyze feasibility of power plants for power generation at low cost. However, the main points have been described as follows:

- Pakistan, is undergoing a serious energy crisis due to continuous increase in electricity consumers which has led to major electricity shortage of 8 -12 hours in rural and urban areas. With this, the industrial, residential and commercial sectors are ominously affected, and it is becoming a big challenge for the Pakistan’s government to provide uninterrupted power supply, in near future. Therefore, current situation urges researchers to explore renewable energy resources.
- Wind energy techno-economic cost analysis with respect to load demand is conducted in this study for supplying power to rural communities at low cost. This can also be helpful to determine the feasibility of developing a wind farm across proposed zones of Pakistan. However, actual annual power production from wind farm investment is applied to evaluate the energy cost.
- However, in this study, after detailed study, authors proposed and highlights the most suitable wind sites such as Pasni (Balochistan Province) and Badin (Sindh Province) for installing wind power generation plants, and it has been analyzed that from these two wind sites, it has a huge wind potential where wind speed blows above the international standards in detail as shown in Table 3.
- It has been analyzed and estimated that at least 2.6 GW power can be contributed from wind plants connected in national grid or can fulfill the demands of rural areas of the proposed sites.
- Additionally, the energy policies of the country, that have been announced over the years as well as the impact that they made on the electricity sector is taken under consideration in this paper.
- This paper develops a roadmap and proposes the wind energy sites that can fulfill the country’s rising energy requirements, whilst being sustainable at the same time. Moreover, this roadmap also identifies and highlights the necessary requirements that our country must undertake to reach its vision to fulfill energy needs and integrating renewable energy sources for power generation at low cost, which is inevitable.
- From this research, it is also concluded that power generated by various prototypes of WTs will suggest the most optimum power through the best probability function,
such as Weibull and Rayleigh distribution parameters. Moreover, this study provides an evocative progression of action, based on the real-time wind data for wind power integration to electrify rural areas across coastal zone of Pakistan.

- Finally, this study is expected to play an imperative role in incorporating wind farms on the proposed sites to facilitate investors interested in investing in Pakistan’s energy sector.

**FUTURE RECOMMENDATIONS**

Recommendations are classified with respect to various goals as discussed below:

- Wind energy has verified from the results that the Pakistan have a huge potential for power generation, which can contribute energy needs along the country side.

- If all sites with acceptable wind characteristics were fully utilized, then Wind energy could contribute to whole country’s energy needs at cheaper per units rates as compared to conventional sources.

- Pakistan should take serious decisions to utilize the free source for power generation and rethink (reconsider) for longer-term data required for the future wind industry.

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