Risk Assessment of a Wind Farm

By

Samreen Siddique

Registration # 201361507MCES64113F

Session 2013-15

Supervised by

Dr. Naseem Iqbal

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Engr. Rashid Wazir

A Thesis Submitted to the Center for Energy Systems in partial fulfillment of the requirements for the degree of

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THESIS ACCEPTANCE CERTIFICATE

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This is to certify that work in this thesis has been carried out by **Ms. Samreen Siddique** and completed under my supervision in USAID funded Center for Advanced Studies in Energy at NUST (CAS-EN), National University of Sciences and Technology, H-12, Islamabad, Pakistan.

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Dedicated to my grandfather, Ilyas Ahmed, who taught me mathematics.

Abstract

Given the current power outages in Pakistan, renewable energy is a basic national need and for this purpose determining potentials of alternative energies is important, one of them is wind energy. Wind power has several advantages. It is renewable, clean, has low operational and maintenance cost, less environmental impact, high capacity factor and a high energy return on investment. Wind speed is the most crucial factor in wind power production but because of its intermittent nature power supply is not continuous. The best practice is to predict wind speed and forecast wind power production with minimum mean absolute percentage error. Studies have shown that accuracy of wind power forecasting is not accurate enough and different models have been applied to get best results. In this study, Auto-Regressive Integrated Moving Average models' Box and Jenkins methodology and Neural Networks Back Propagation method have been applied for the wind power estimation for the coastal areas of Baluchistan. Four -year monthly mean wind speed data (2009-2012) provided by Pakistan Meteorological Department have been used and based on these data, monthly mean wind speed has been predicted for the next four years (2013-2016) using two approaches, Autoregressive Integrated Moving Average models and Neural Networks Back propagation method using MATLAB. Basing the study on the obtained wind speed forecasts, this study aims to determine the technical feasibility of a wind farm along the coastal line of Baluchistan, Pakistan. Key objective is to estimate wind power potential at low, medium and higher heights and suggest a hub height and turbine most suited to the conditions. 317 turbines of up to 5MW of different manufacturers were examined at different heights (60m, 80m, 100m, and 120m). Optimum height and model of turbine has been determined according to the wind speed at different locations to obtain maximum possible capacity factor. Furthermore, a financial study has also been carried out considering the average wind speed, optimized hub height and rating of wind turbine determined from technical analysis and country's tariff rates. This part of the study determines the pros and cons of investing in a wind farm at different locations in Pakistan. Finally a unique storage technique using molten salts has been discussed and modelled using MATLAB SIMULINK.

Key Words: *Wind Power Forecasting, Wind turbine, Wind Farm, Neural Networks, Backpropagation method, Autoregressive Integrated Moving Average (ARIMA)*

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List of Abbreviations

AEDB	Alternative Energy Development Board
ANFIS	Adaptive Neuro-Fuzzy Inference Systems
ANN	Artificial Neural Networks
AR	Autoregressive Model
ARIMA	Autoregressive Integrated Moving Average
BP	Back Propagation
BPNN	Backpropagation Neural Network
BT	Bayesian Theory
CWT	Continuous Wavelet Transform
DWPT	Discrete Wavelet Packet Transform
DWT	Discrete Wavelet Transform
FNN	Feed forward Neural Network
GDP	Gross Domestic Product
KF	Kalman Filter
MAE	Mean Absolute Error
MAPE	Mean Absolute Percentage Error
MSE	Mean Square Error.
NWP	Numerical Weather Prediction
PM	Persistent Model
PSO	Particle Swarm Optimization
RBF	Radial Basis Function
RBFNN	Radial Basis Function Neural Network
RNN	Recurrent Neural Network
SVM	Support Vector Machines
VAR	Vector Auto regression Model
WD	Wavelet Decomposition
WPD	Wavelet Packet Decomposition

Chapter 1: Introduction

1.1 Background

By June 2014, the worldwide wind capacity had stretched around 336.327 GW and 17.6 GW were connected in beginning of 2014. The introduced limit of wind turbines is ascending at a yearly rate of 25% around the world. This demonstrates a developing trend for the wind electric power each year. Inferable from the expansion in trend, around 4 percent of the world's aggregate power demand can be satisfied by the wind turbines [1]. This quick advance in the current years is a direct result of declining hardware costs, vulnerability in the regular fuel costs, government arrangements and motivating forces, condition concerns, attention to green power, requirement for vitality security and expanding carbon hazard [2]. It has been anticipated that inferable from the expanding awareness about their advantages, solar and wind powered will be the least expensive types of energy sources for biggest energy markets of Asia inside ten years [5]. Estimations additionally evaluate that by 2030, one fifth of the planet energy demands can be met by wind. This shows ecological as well as monetary advantages for all nations. This chapter endeavors to highlight the innovation and development of wind power in Pakistan.

1.2 Energy Situation of Pakistan

Roughly 1.3 billion individuals are living without power around the world; 66 percent of them live in ten nations one of them being Pakistan [6]. Despite the fact that energy demand has tormented Pakistan since its inception in 1947, this national issue got consideration just in this century. From 1947 to 1980s, local resources and assets could meet just 66% of the energy demands [7]. Amid 2011-12, blackouts reached 8 to 10 hours every day in metropolitan cities and over 20 hours in other areas [9]. The aggregate energy deficiency of more than 6000 MW restricted the production activities of Iron and Steel, Petroleum, Engineering Industries and Electrical thus diminishing GDP rate by 0.2 pints in fiscal years of 2010-11 and 2011-12 [7]. Thus, the general welfare of the nation was influenced [10]. Presently in the current year, the cost of unrefined petroleum dropped to half of its past cost, from 11,298 rupees for each barrel in December 2013 to 6, 112 rupees for each barrel in December 2014 [11]. Likewise, Pakistan's energy insights from 2012 gauge that a yearly power utilization of mere 74 billion kWh consumption for every capita is 456.64 kWh [12]. Still, Pakistan is among the ten most energy deprived nations on the planet. The energy capacity in Pakistan is more than the energy generation and the energy being generated in less than the energy demands [14].

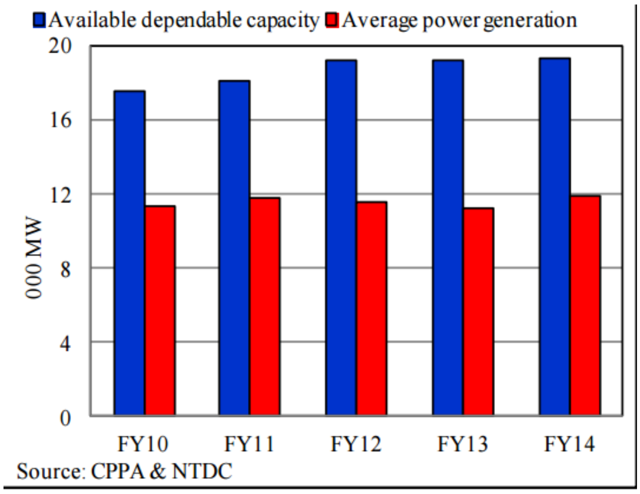

Figure 1.1.1- Generation and capacity in past five years (FYs) [13]

Over all, studies show that in past years, because of dependence on petroleum derivatives, climatic changes, increase in oil costs, and insufficient innovative advancements Pakistan is not very successful in fulfilling the energy demand of its citizens [9][15][16]. It has been demonstrated in the that in Pakistan, the energy utilization, power generation and economic development are interrelated [17][18][19]. This clarifies the financial development of Balochistan, a territory that consists of 44 percent of the aggregate land mass yet just 10 percent populace in the region has access to power. By broadening its energy sources through wind assets, Pakistan can achieve energy security [4].

The drive to change Pakistan's energy situation started in the 1980s when nationwide power blackouts debilitated any odds of economic improvement in the nation and disabled the country. To tackle this emergency, the Pakistani government ordered its first private power scheme in 1985 [20][21].

1.3 Current work

The main questions addressed in current work are:

- Is wind energy a feasible option for Pakistan and if its intermittency can be addressed?
- Can statistical and artificially intelligent models accurately forecast wind speed time series?
- Is the wind resource at specific locations in Pakistan good enough for a large scale wind farm?
- Is wind power a technically feasible option to the ongoing energy crisis?
- Is wind power a financially feasible solution to the ongoing energy crisis?
- What are risks and hazards involved in the development of wind power in Pakistan?
- What is the optimum turbine rating and hub height in different locations of Pakistan?
- What are the environmental impacts involved?

1.4 Study Objectives

- To study and review the wind power developments in Pakistan since its birth
- To review the different forecasting techniques used globally for wind speed time series
- To implement artificial neural networks method and statistical tools for wind speed time series forecasting

1.5 Thesis organization

The research work in this dissertation has been presented in six chapters. First chapter is dedicated to the energy situation of Pakistan, need of wind energy and wind power developments in the region. Second chapter is an exhaustive literature survey of the risk analysis methodologies, forecasting models and wind energy scheduling methods being used around the globe at present and in the recent past. Third chapter is a brief overview about the global and local sources of wind in the country. Fourth chapter is a detailed explanation of the two models being used in the study that are Autoregressive Integrated Moving Average model and Neural Networks Backpropagation method. Fifth chapter presents the results obtained by the two models and a comparative analysis of both models when used for wind speed time series forecasting of four cities of Pakistan. The sixth chapter concludes this document by presenting a complete technical and financial assessment of wind farms in the selected areas of the country.

1.6 Summary

This chapter is a review of the energy sector in Pakistan, the importance of wind power, the present energy supply lag and the wind power developments happening in the country. Pakistan has been behind the rest of the world in developing the renewable energy sector but now 3 grid interconnected wind farms have been supplemented to the grid giving off more than 150 MW.

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Chapter 2: Literature Review

2.1 Time series

A collection of measurements or observations made in a sequence with respect to time is called a time series. These measurements can be continuous or discrete depending upon the requirement of the experiment. Forecasts are done when future values are computed through present and past values. Wind speed is highly intermittent and has a volatile time series and is considered one the most difficult parameters to model and forecast. There are many various types of forecast:

- Judgmental forecasts are based on intuition and other relevant parameters
- Univariate forecasts depend only on present and past values of one time series
- Multivariate forecasts depend on present and past values if multiple time series of various parameters
- Out of sample forecasts is when entire data in hand is used to forecasts a future value. Since the entire data is used there is no immediate way of validating the forecast except to wait for the future values to be recorded.
- In sample forecast on the other hand take one part of the data to be forecasted and the next set of data is used to check and validate the model and the forecast. If found appropriate the next set is then used for forecast.

2.2 Advantages of wind speed forecasting

It has been reported that it is feasible to use the mathematical formulation to predict wind speed trends for any uses in wind-energy systems [1], Thereafter, a risk analysis was performed through two methodologies (Monte Carlo and Box & Jenkins) made it possible to consider the wind speed volatility and to compute the expected value of financial indicators of the project. Both methodologies, show a strong similarity with those obtained in the deterministic analysis [2].

A recently conducted survey on the amalgamation of Operation Research and Management Science and weather forecasts stated that the electrical power sector can profit from employing advanced techniques such as neural network using weather data, to forecast demand and supply [3]. Wind speed forecasts help wind industry to select sites, layout of facility, and to determine the prime number of turbines[4]. Also, wind power forecasts that are based on wind speed forecasting influence prices in electricity markets [5].

Wind speed forecasts can be categorized in three types:

- Long term (over years) - long term forecasting is mostly used for wind farm designing and to calculate the generation capacity of wind farms yearly.
- medium term (weeks - months)
- short term (minutes - days) forecasting: for calculating short term demands and supply needs

2.3 Models for wind speed forecasting

Most popular forecasting models are:

- **Persistent method**

Persistence Method is the least complex method for delivering a figure. The persistence technique expects that the conditions at the season of the conjecture won't change

• Autoregressive Integrated Moving Average models including f-ARIMA, s-ARIMA are measurable models for expectation of time arrangement. This model has been examined in detail in this chapter.

• Artificial neural systems including Backpropagation neural systems (BPNN), repetitive neural systems (RNN), and Multi-Layer Feedforward neural systems are an interconnected gathering of hubs, similar to the tremendous system of neurons in a brain. Every round node speaks to an artificial neuron and an arrow speaks to an association from the yield of one neuron to the contribution of another. By setting weights of neurons estimates should be possible. This has been clarified more in the upcoming chapter.

• Support Vector Machine (SVM) is a discriminative classifier that was characterized by an isolating hyperplane formally.

• Fuzzy Logic is a method to foresee processing in view of "degrees of truth" unlike the standard practice of "truth or false" (1 or 0) Boolean rationale on which the current PCs are based.

Auto Regressive (AR) models were first presented by Yule in 1926. They were thus supplemented by Slutsky who in 1937 exhibited Moving Average (MA) plans. Wold (1938) joined both AR and MA conspires and demonstrated that ARMA professional cesses can be utilized to model all stationary time arrangement the length of the fitting request of p, the quantity of AR terms, and q, quantity of MA terms, was properly calculated [6].

Utilizing a factual approach, Box and Jenkins have built up the coordinated autoregressive moving normal (ARIMA) procedure for fitting a class of direct time arrangement models. Analysts in various ways have tended to the limitation of linearity in the Box-Jenkins approach. Many variable forms of different ARIMA models have been produced. Likewise, a lot of writing on inalienably nonlinear time arrangement models is accessible. The stochastic way to deal with nonlinear time arrangement can fit non-straight models to time arrangement information, however gives measures of instability in the evaluated display parameters and additionally gauges created by these models. It is the stochastic approach that again empowers the detail of instability in parameter gauges and figures. All the more as of late, ANN have been examined as a contrasting option to these nonlinear model-driven methodologies.

In view of their qualities, ANN have a place with the information driven approach, i.e. the examination relies on upon the accessible information, with little from the earlier justification about connections amongst factors and about the models. The way toward developing the connections between the information and yield factors is tended to by certain broadly useful "learning" calculations.

A few downsides to the pragmatic utilization of ANN are the perhaps long time expended in the demonstrating procedure and the substantial measure of information required by the present ANN innovation. Accelerate is being accomplished because of the noteworthy advance in expanding the clock rate of present processors. The requests on the quantity of perceptions remains however a hard open issue. One reason for both issues is the absence of positive nonspecific system that could be utilized to plan a little structure. The greater part of the present systems utilize systems, with an extensive number of parameters ("weights"). This implies extensive calculations to set their esteems and a prerequisite for some perceptions. Lamentably, by and by, a model's parameters must be evaluated rapidly and only a little measure of information are accessible. In addition, some portion of the accessible information ought to be kept for the approval and for execution assessment methods.

Many studies have been done to test the execution of various estimating models and decide their skills in various situations. The aftereffects of a review in Jeddah on a testing information showed that the neural system approach beats the AR model as shown by prediction chart and by the root mean square mistakes [7]. Another review presumed that ARIMA model is a feasible option that gives acceptable outcomes as far as its prescient execution [8]. In 2002, a comparison of Box-Jenkins ARIMA and ANN (multilayer feedforward and recurrent) was carried out. ARIMA and RNN beat the feedforward model in short-term forecasting. Both ARIMA and RNN were declared promising tools for time series prediction [9]. Numerous new models have likewise been presented, for example, a model in view of estimates from a numerical weather prediction model (HIRLAM) was presented, and the conjectures were made locally substantial by the WASP program. The model was contrasted with the diligence model and figures by people (utility dispatchers) with great outcomes.

A half and half system that joins both ANN and ARIMA models is proposed to exploit the one of a kind quality of ANN and ARIMA models in straight and non-linear displaying. Test comes about with genuine informational collections demonstrate that the consolidated model can be a powerful approach to enhance guaging precision accomplished by both of the models utilized independently [12].

At the point when un-preprocessed information is utilized, neural systems are not ready to catch occasional or drift varieties adequately with the crude un-preprocessed information. De-trending and de-seasonalization has been discovered successful [13]. Ideal on-line learning calculations was utilized for preparing the locally repetitive systems in view of the recursive prediction error (RPE) calculation, show improved execution, as far as meeting pace and the exactness contrasted with customary inclination based strategies. These models outflanked the climatic and time-arrangement models [14]. Another examination portrays a factual determining framework for the transient forecast (up to 48 h ahead) of the wind vitality creation of a wind cultivate. The framework needs to manage exceedingly nonlinear connections between the factors included and the forecast framework would create expectations for option wind ranches [15]. A subjective approach for the correlation of models were surveyed in a review. Earnest requirement for the attainability of operational on-line devices has been unmistakably distinguished [16]. Another technique in view of direct expectation was proposed in conjunction with the separating of the wind speed waveform. Viability of straight forecast technique was built up [17]. Versatile gauge mix system was proposed. The option mix technique is actualized with time differing coefficients taking into account non stationarities, and time fluctuating estimation is made utilizing a versatile overlooking factor[18]. Hybridization of canny strategies, for example, ANNs, fluffy frameworks and ARMA so that the last model could beat the individual methodologies [19]. Differing setups of ANN were created and looked at through blunder measures, ensuring the execution and exactness of the picked models. Distinctive number of layers and neuron were tried. The easiest model of two layers, with two info neurons and one yield neuron, was observed to be best for the transient wind speed anticipating research examine in Mexico [20]. ARIMA model was observed to be superior to Backpropagation NNT for brief time-interims to conjecture (10 minutes, 60 minutes, 2 hours and 4 hours) [21]. A bibliographical study of improvements in the field of wind speed and power anticipating considers that NWP models are great at foreseeing huge scale range wind speed and are utilized as contributions to ARIMA, ANN and so forth. Persistence models are utilized for here-and-now prediction [22]. Neural systems have solid learning and preparing capacities. Fuzzy rationale models outflank others with thinking capacities [23]. The utilization of f-ARIMA and s-ARIMA was analyzed to model and anticipating day ahead twist speeds on the 24h and 48h horizons. Proposed display beat the constancy show [24]. Another system in wind speed forecast in light of fluffy rationale and fake neural systems was proposed which has altogether less govern base and expanded assessed wind speed precision. Applying the proposed way to deal with counterfeit neural system prompts less neuron numbers and less learning time handle alongside precise wind speed forecast comes about. The test comes about show less computational time and better wind speed forecast execution [25]. A complete examination think about on the utilization of various manufactured neural systems in 1-h-ahead wind speed estimating to be specific, versatile direct component, back engendering, and spiral premise work reasoned that no single neural system display outflanks others generally as far as all assessment measurements. In addition, the determination of the sort of neural systems for best execution is additionally reliant upon the information sources [26]. Another approach of coupling two models was utilized to such an extent that

ARIMA models were first used to do the wind speed estimating and afterward with the got blunders ANN was incorporated considering the nonlinear propensities ARIMA couldn't distinguish. Hybrid model beat the individual models particularly where direct and nonlinear inclinations are discovered [22]. ANN in blend with wavelet change was proposed for here and now wind control gauging [27]. ARIMA was utilized to distinguish and amplify the straight structure in information and after that a neural system is utilized to foresee. Proposed models outflanks singular models and customary half and half models [28]. ARIMA, ANN and ANFIS have been utilized to estimate power production of a wind farm and thought about. Too long preparing period brought about a slight diminishing in execution. Determining exacerbates with an expansion in preparing period [29]. Audits on various devices with different strategies utilized for creating wind cultivate control forecast considering distinctive time scales have likewise been talked about [30]. Estimation blunders tend to diminish as the quantity of reference stations increments. On the off chance that information signs of precise wind bearing and wind speed are utilized then the quantity of reference stations required to accomplish a specific decline in blunder is lower [31]. Neuro-fuzzy frameworks with ARIMA models is proposed for time arrangement anticipating. Molecule swarm enhancement and recursive minimum squares are joined together for the half and half learning technique [32]. Two bolster forward neural system structures were inspected for their capacity to evaluate the hourly wind speed [33]. Comparative analysis of multivariate and univariate ARIMA models by RNN was done. Multivariate performed better than univariate and RNN performed better than ARIMA models [34]. NWP methods from worldwide to nearby scale, ensemble anticipating, upscaling and downscaling processes, factual and machine learning approaches, execution of various methodologies over various time skylines have been talked about. Hybrid methods offer the best results combining the capabilities of NWP and of statistical and machine learning [35].

Later on, hybrid models ARIMA-SVM and ARIMA-ANN were investigated. The research concluded that hybrid models may not be able to produce superior performance over all time horizons but they definitely are a viable option [36]. Execution examination of a transient wind speed forecast methods in view of soft computing models planned on BPNN, RFBNN, ANFIS. Performance was seen to improve drastically with SD preprocessing [37]. Wavelet Packet-ANN model was found to be best when compared with ANFIS, Neuro-Fuzzy, PM etc. [38]. Blended ARMA display that joins direction of the wind into here and now wind speed and wind control yield figures [39]. The conjecture show used the Levenberg Marquardt BP calculation with a tap delay for expectation of power and wind speed era was proposed for a 5 day wind speed and power figure [40]. The exactness of a direct blend of estimates relies on upon the related joining weights principally relies on the related consolidating weights. Discovering the proper weights is as yet difficult. Wavelet Packet-ARIMA-BFGS, Wavelet-BFGS and Wavelet Packet-BFGS have attractive execution in the wind speed expectations, while the Wavelet Packet-ANN model is the best among all of them [38]. The execution of the half breed ARIMA-SVM and ARIMA-ANN were superior to those of single SVM, ARIMA and ANN models [36].

2.3.1 Autoregressive processes

A procedure $\{X_t\}$ is called to be an autoregressive procedure of order p (truncated AR (p)) if

$$X_t = \varphi_1 X_{t-1} + \varphi_2 X_{t-2} + \cdots + \varphi_p X_{t-p} + Z_t \quad (2.2)$$

If $|\varphi| < 1$, then it can be demonstrated that the procedure is stationary.

2.3.2 Moving average processes

A procedure $\{X_t\}$ is said to be a moving average procedure of order q (shortened MA (q)) if $X_t = Z_t + \theta_1 Z_{t-1} + \cdots + \theta_q Z_{t-q}$ (2.3)
Method could well be needed to develop predictions. This correlogram is possibly the utmost valuable tool in time-series exploration next to the time plot. Symbolize the perceived time sequence by $\{x_1, x_2 ... x_N\}$. The sample auto covariance factor at k lag number is typically deliberated by:

$$c_k = \sum_{t=1}^{N-k} (x_t - \bar{x})(x_{t+k} - \bar{x}) / N$$

(0.1)

For k =0, 1, 2…

The selected factors should create the lowermost residue-terms. This may be achieved employing the “Maximum-Likelihood-Approximation” or the “Yule–Walker-Approximation”. The typical technique is to assess the arbitrariness of the residue-terms by means of “Ljung–Box-Statistics” and “P-numbers” that are non-weighty show that the residue-terms are not in correlation and the suggested model is appropriate to fit the previous history data.

Summary

Literature that shows the respective advantages of artificial neural networks, ARIMA statistical models and support vector mechanisms is widely published and recognized. No one of them has been proven to outdo the other techniques in all the parameters that are used to measure success of each model (error terms, goodness of fit, forecast accuracy, precision etc.) Typically what happens is that statistical models ARIMA are able to capture and represent the linear relationships or linearity in the expressions but lacks the ability to show a solid prediction of non-linear expressions or relationships in the data. This is where the performance of artificial neural networks and support vector mechanism come into play. Both of them have been shown to outperform statistical methods. In short, this can be summarized that the performance of a certain model depends upon the data and how linear it is. To get the best of both worlds, hybrid methods have been developed that use ARIMA for linear relationships and the other models for non-linear relationships. This dynamic approach is believed to be the best so far and considered a great strategy for series forecasting universally.

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Chapter 3: Sources of wind

The largest province of Pakistan, Balochistan is of particular interest in this city because of its vast land area of 347,190 sq. km. It makes 44% of the total land area of Pakistan. Because of its rough terrain, hot and dry climate, desert tracts and rugged mountain ranges it has not been very populated. Balochistan province includes the subsequent thirty two regions, viz.: Sherani zilla, Nasirabad zilla, Jhal Magsi zilla, Lehri zilla, Kohlu zilla, Barkhan zilla, Sibi zilla, Kharan zilla, Dera Bugti zilla , Bolan zilla, Qilla Pishin zilla , Khuzdar , Chaghi , Quetta, Lasbela, Gwadar, Harnai , Washuk , Sohbatpur , Jaffarabad region, Nushki region, Qilla Abdullah region, Saifullah region, Loralai region, Mastung region , Kalat region, Panjgur region, Zhob region, Kech region, Ziarat region, Awaran region, Musakhel region [1].

3.1 Wind cells

Global wind sources in the coastal area of Pakistan can be explained by the existence of Hadley cell in this area lying in the latitude lesser than 30^0 N. The area in Pakistan from Muzaffargarh till the Arabian Sea shore is all included in this Hadley cell. Quetta at latitude of 30.18° N and longitude of 67.0° E), Dera Ghazi Khan at latitude of 30.05° N and longitude of 70.63° E , Multan at latitude of 30.19° N and longitude of 71.46° E etc. lie slightly above the imaginary border of the Hadley cell, thus are a part of the Ferrell cell. Most part of Sindh and Balochistan is a part of the Hadley cell. In the Hadley cell, winds that blow are called 'trade winds'. Surface winds flow toward the equator as shown in Figure-3.1, while the movement upward is headed for the poles. In the cities near 30° (Quetta, Dera Ghazi Khani, Multan, Bahawalpur) air starts to incline to the surface in what is known as the subtropical crests which are basically subtropical high-pressure belts. As the air sinks here which can be termed as the subsiding air is comparatively dry. The reason is that as the air is descending in this region the temperature is increasing while the absolute humidity does not change and hence it is a constant. Consequently, the relative humidity of the air is lowered. This air with a higher temperature and lower relative humidity i.e. dry and warm air mass also termed as the "superior air mass" and typically exists in directly above an oceanic humid air bulk. In short, the temperature is increasing with an increase in height. This upsurge of temperature with height is called temperature inversion.

Figure 3.1- Map of Pakistan with respect to latitude. 30 degrees North and below indicates Hadley cell

Cells known as the Ferrell cell, and Polar cell are shown in Figure 3.2. Cities such as Chitral (35.8461° N, 71.7858° E), Mongora fall among the highest latitudes of Pakistan and are a part of the Ferrell cell.

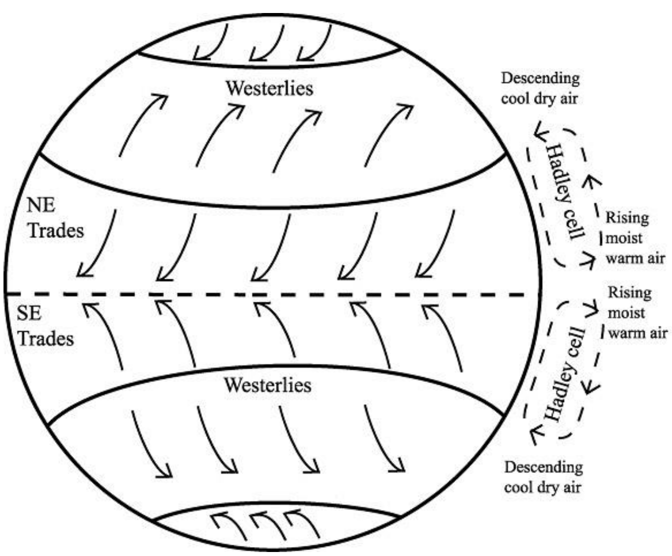

Figure 3.2- Trade winds directions in Hadley cell and Westerlies in Ferrell and Polar cells.

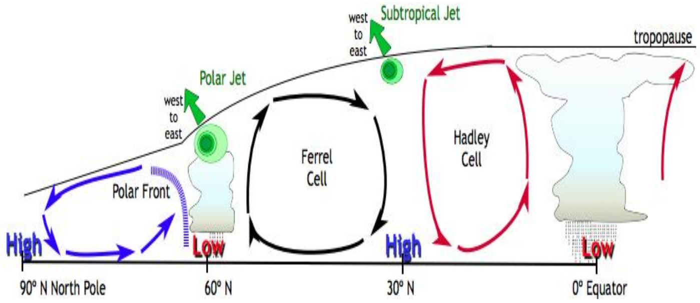

Figure 3.3- Hadley, Ferrell and Polar cells w.r.t. latitude. (Image courtesy: CMMAP)

In case of diverse atmospheric dynamics, it is highly likely that one hefty toppling circulation in each hemisphere may happened that results in an equable approximately uniform climate. This may happen when the wind from the lesser latitudes conveys heat to the higher latitudes and thus creating an equable region. Brian Farrell offered this notion in 1990 and was in favor that for the duration of equable climates, the Hadley Cells were encompassing all over from the equator to the poles [2].

3.2 Monsoon

Monsoon particularly the summer monsoon in Pakistan occurs as follows:

1. The prevalent wind course varies as a minimum of 1200 amid January & July.
2. The mean value occurrence of prevalent wind in January and July ought to surpass by forty percent.
3. The average resulting winds surpasses 3 meters/second in a minimum of one month.
4. In the 5° latitude and longitude regions, less than one cyclone anticyclone modification ought to take place every 2 years in either month (C.S. Ramage, 1971).

3.3 Other Sources of Wind

The power of the surface blowing winds above any site is controlled by a number of factors:

- The altering impacts of the existing landscape- the topography
- The extent of the pressure ascent right above the planetary boundary level
- The atmospheric steadiness in the boundary layer

Halley (1686) & Hadley (1735) suggested that differential heating was the primary cause of annual cycle of monsoon circulation. In the case of coastal areas of Pakistan, this is provided by the differential heating of land and the sea. Winds are more likely to be stronger as the coast is approached. This is because of the added pressure gradient. This supplementary pressure rise is delivered by the thermal disparity between the two landscapes: the land and the water body. Pakistan Meteorological Department's annual report of 1986 studied wind potential along the Arabian Sea coasts and concluded that windmills may be more feasible at this site. Apart from this being a thumb rule globally, it is specifically because the coastal winds are less intermittent in nature i.e. there are fewer time slots when there is negligible wind. Hence the wind patterns are ore persistent and rigorous than any other region in Pakistan. Diurnal wind speed patterns were plotted by Y. Z. Jafri et al. for Quetta 1984-85 with peak wind speeds greater than 7m/s in summer, fall and spring season [11]. It is observed that dry and semi-parched are predominantly appropriate in the case of solar and wind hybrid systems or combined arrangements due to more proportion of sunny and cloudless days and comparatively robust wind patterns. Over two thirds of the country comprises of arid regions [7]. Shoreline and off-shore areas have greater prospective as compared to internal regions. Landscape and the prevalent topographies are also significant dynamics, for instance, hill being specific specimens of key locations [12].

In Pakistan we observe that Sun starts scorching down the southern areas of Pakistan by the end of March or early April. April and May are the months during which soaring heat absorbed by the southern regions in Pakistan that are, Sindh and southern part of Balochistan, here this raises temperatures as high as up to greater than 40 degree Celsius during daytime. The irregular topographical feature of the inland landmass in Asia gives upsurge to great thermal dissimilarity between land located at the north and the ocean that is at the south in both the seasons: winter and summer, which is very crucial factor in most pronounced circulation in this part of the globe.

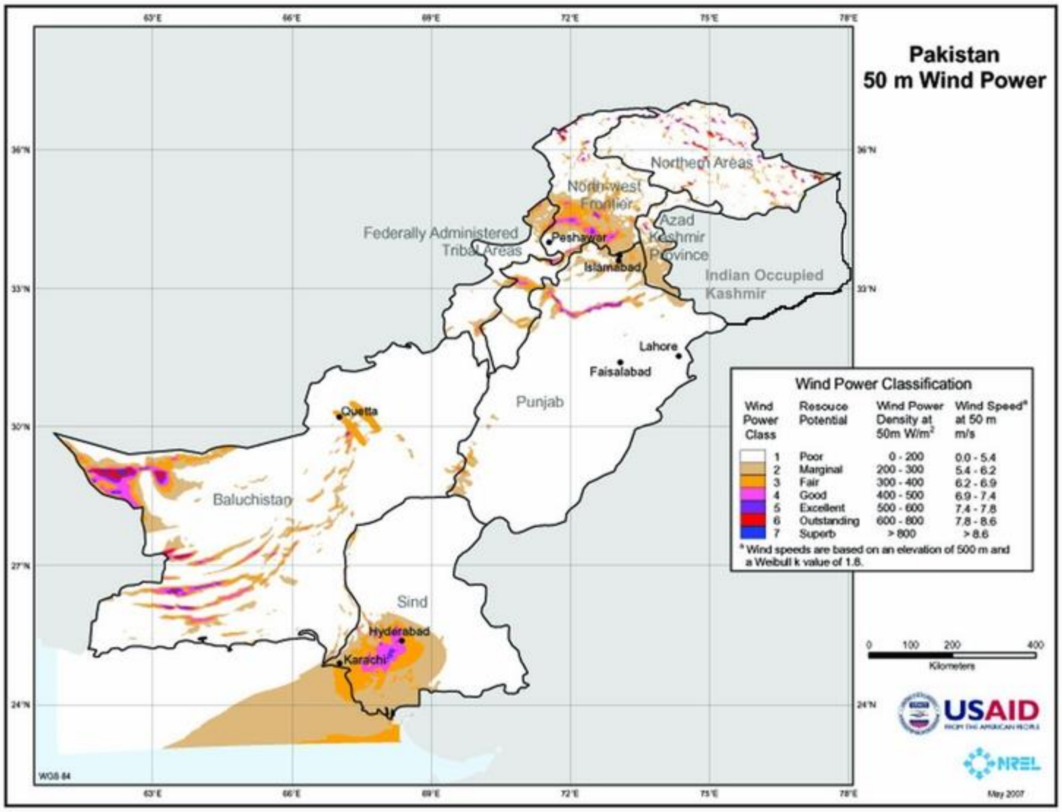

Figure 3.4- Wind potential in Hadley cell (latitude less than 30°) in Pakistan

The coastal cities of Pakistan like Karachi, Ormara, Pasni and Thatta etc remain under the grip of thick layer of low clouds under the influence of strong southwesterly flow from north Arabian Sea on to land [13]. Table 3.1 shows the wind speeds in the coastal areas of Balochistan. Data courtesy: NASA data center.

Table 3.1- Coastal areas of Balochistan and their wind speeds at 50m

Area	Location	Wind speed at 50m (m/s)
Ormara	25.2° N, 64.63° E	5.20
Jiwani	25.05° N, 61.73° E	5.19
Gwadar	25.12° N, 62.32° E	5.18
Pasni	25.26° N, 63.46° E	5.14
Nokundi	28.81° N, 62.76° E	5.91

Summary

This chapter is an effort to understand the sources of winds in Pakistan in the light of different wind cells, Hadley, Ferrell and Polar. The atmospheric circulations have been discussed briefly as well as the role of monsoon in the wind circulations. Both global and local sources of wind interact to determine the wind potential of that particular area. In case of coastal belt of Pakistan, low level local jet streams, heat mass, temperature gradient, tropical jets – all contribute towards a net flow of wind.

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Chapter 4: Methodology

4.1 Methodology

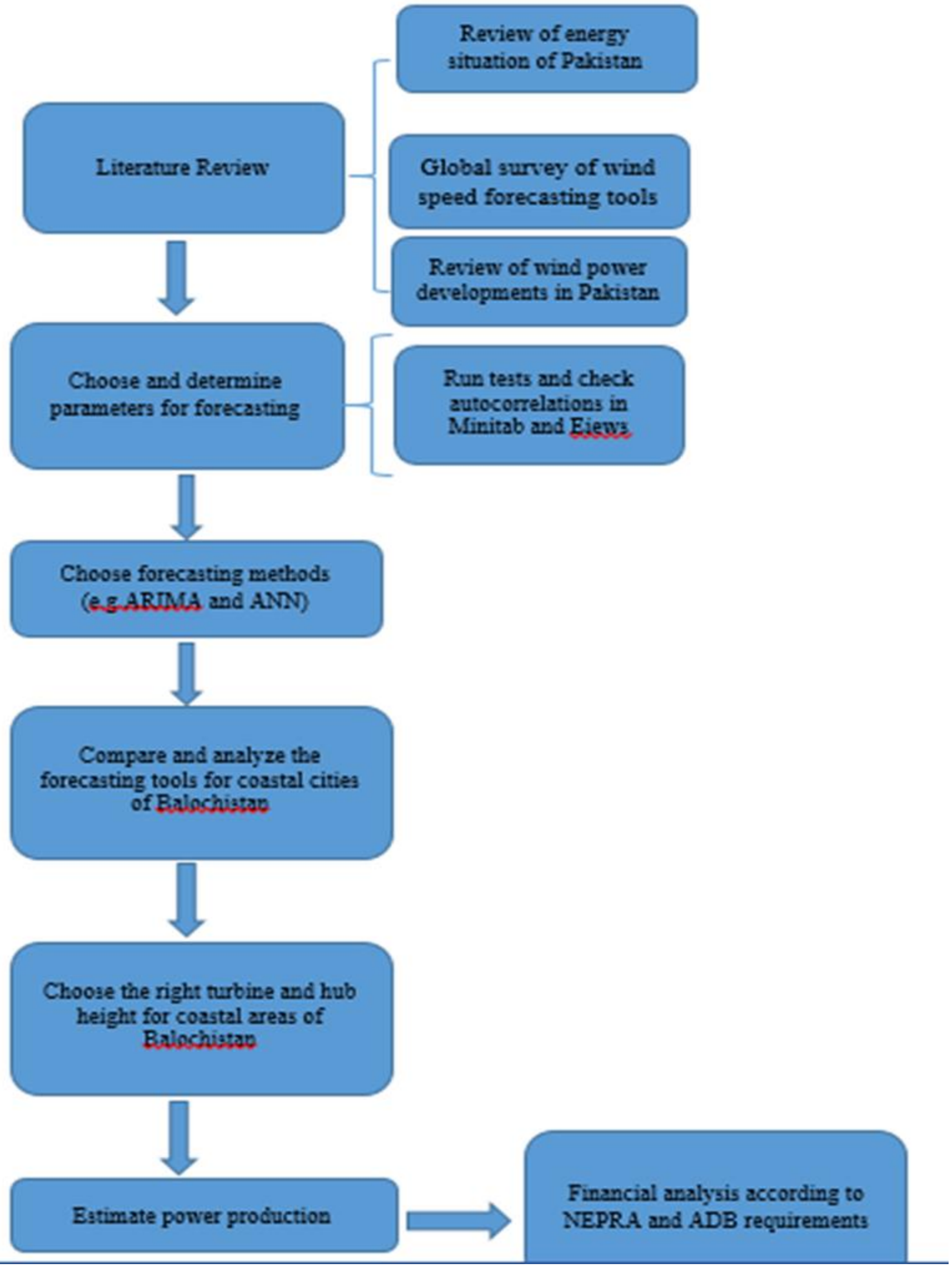

Figure 4.1- Methodology

Firstly, a time series graph is required for observation and analysis of the data. This time series graph may also aid in determining whether any parameters need to undergo transformation before the core study. For instance, if the variance value is observed to be increasing with the mean then there is an ascending tendency in the time plot. In this case, transformation might be appropriate and applied so that the variance value is made stable i.e. it is made to be it homoscedastic. Also, if the observed series appears to be skewed or inclined, therefore to make the data appear of more normal distribution a transformation may be applied. Lastly, if the cyclical effect seems multiplicative, it is better that it be made additive by applying transformation to eliminate the non-linearity as the linearity is easier to handle in a time series evaluation. Data cleaning involves the following steps:

- Any missing observations are filled in by interpolation
- Outliers should be modified.
- Obvious errors are identified and corrected
- Vigorous approaches decrease or down weight the impact of extreme (unlikely null, negative or way higher than usual) observations and are progressively more .employed.
- Interim estimates may also be altered to handle the outliers or extreme observations.

Consider that at time'‘t' the mean is represented as μ_t. This trend is a simple linear approach often called as "global-linear" trend or deterministic trend. Conversely, existing approach is to usually evade representations comprising a deterministic time function and global models and prefer the local one instead. Hence, the trend is such modelled that it is evolving in a stochastic or random way rather than the deterministic way.

Local linear trend can be represented in many way one of which is that the factors α and β are allowed to undergo evolution through time such that $\mu_t = \alpha_t + t.\ \beta_t$

Here α_t represents the local cut off term while β_t represents the local gradient.

Another point of significance is to understand that the absence or presence of seasonal patterns in the statistical past data also affects how the time series is treated and the overall trend is handled in the data.

If yet to come numbers can be projected exactly from preceding numbers, then such a time series is called "*deterministic"*. This does not happen very often and more often than not the given the series are '*stochastic'* by nature, the forthcoming values can, at best, be partially calculated by preceding numbers. Stochastic process is such a model which is developed for a random time series. Stochastic method is a group of unsystematic parameters that are indexed by means of time, and are represented as X_1, X_2…, or in general by X_t, a discrete value of time. *Stationary* procedures are that in which the characteristics of the fundamental model are not varying with the time. If the 1st and 2nd moments are not infinite and hold finite value, constant through time then such a stochastic process is called '2nd order stationary'. Generally the 1st moment is the mean value expressed as E [X_t] and the 2nd moment is generally the covariance (for varying values of k and t), between X_t & $X_{t+k.}$ Such a covariance is named as "auto-covariance". When the value of lag at k is zero then this is actually the variance, "Var [X_t]", a special case of auto-covariance. Therefore a procedure is 2nd-order stationary if the mean E [X_t] is finite and constant represented as μ, and if the variance Var [X_t] is finite and constant represented as σ^2, and in general if the lag k is the only influencing factor for the auto covariance function such that:

Cov. $X_{t,}$ $X_{(t+k)} = E (X_t - \mu)(X_{t+k} - \mu) = \gamma_k$

The set of auto covariance coefficients γ_k for values of k from 0 to n make up the auto covariance term of this process. Here, γ_0 is the σ^2 or the variance. 2nd -order stationarity is often named weak stationarity or the covariance. The auto covariance function is frequently regulated to form a set of coefficients of autocorrelation ρ_k, such that,

$\rho_k = \gamma_k/\gamma_0$ k values ranging from 0 to n. The autocorrelation coefficients ρ_k makes up the autocorrelation function (ACF). ρ_k determines the lag k correlation between (X_t and $X_{t+k)}$ for a stationary process. Because here, $\rho_k = \rho_{-k}$ the auto covariance function is actually an even lag function having the typical characteristic of correlation i.e. $|\rho_k| \leq 1$. Other added valuable functions corresponding to the ACF comprise the PACF- partial autocorrelation function that basically determines any excess lag k correlation at that may not be accounted before by lower lag autocorrelations that may not have been taken into account by lower lag autocorrelations.

Spectral density function is a substitute means of relating to a 'stationary stochastic process'. This spectrum which basically is the discrete Fourier transformation of $\{\gamma_k\}$, explicitly: f (ω) = 1 $f(\omega) = \frac{1}{\pi}(\gamma_o + 2\sum_{k=1}^{\infty}\gamma_k \cos \omega k)$

4.2 **Models for wind speed forecast**

The models that was used in this case is Autoregressive integrated moving average model, written as ARIMA (p,d,q) (P,D,Q) S , here (p,d,q) are the non-seasonal parameters of the model and (P,D,Q) are the seasonal parameters while S is the amount of periodic frequency in one season (Cadenas & Rivera 2007). This approach is carried out in four stages:

Artificial neural networks method is one of the most accepted methods gradually making it place since the last decade for different types of forecasting be it wind speed or other factors. It is already being used in business models, marketing and production forecasts throughout the world. Training procedures were established comprising the back-propagation procedure, the Levenberg Marquardt method to attain the negligible number of network inaccuracy (Sfetsos 2002). Suitable treatment of the raw statistics is essential for acceptable implementation in the neural networks (Zhang & Qi 2005).

Summary

This chapter discusses the method of the research, the two models which are to be compared namely ARIMA and ANN and also the steps required to carry out the analysis. Identification, estimation, testing and prediction are the initial steps for wind speed forecasts. After the forecast have been determined, wind power calculations and financial analysis is carried out.

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Chapter 5: Data Analysis

5.1 Data assortment and treatment

Wind speed data was obtained through PMD (Pakistan Meteorological Department) for 2009 to 2012 of four cities Pasni, Jiwani, Ormara and Gwadar all are the coastal cities of Balochistan.

The time speed series of these four cities is as shown below 5.1 – 5.4**.**

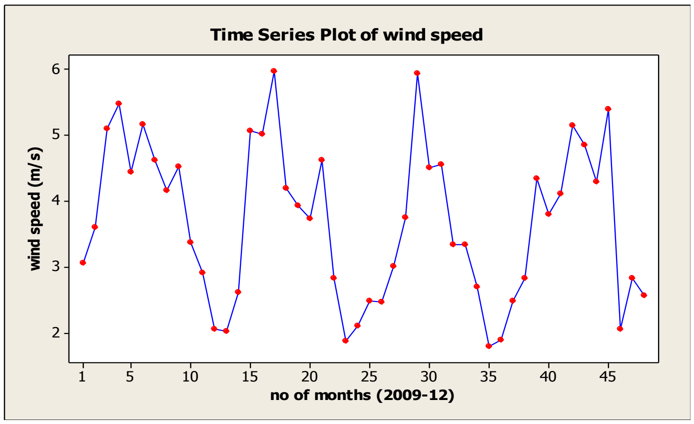

Figure 5.1-Ormara's wind speed plot respective to time

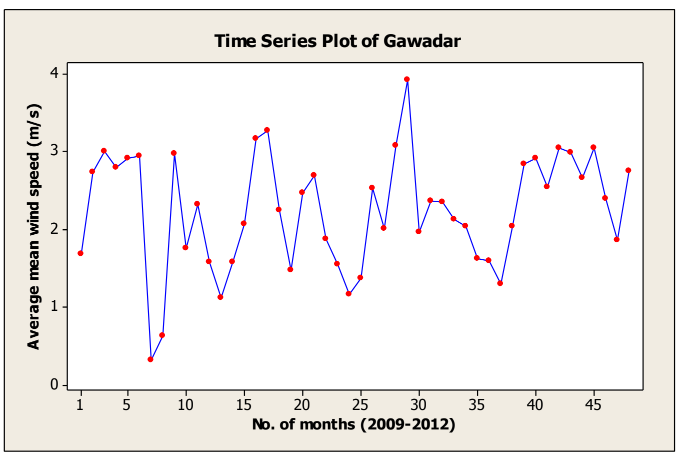

Figure 5.2- Gwadar's Wind speed time series plot

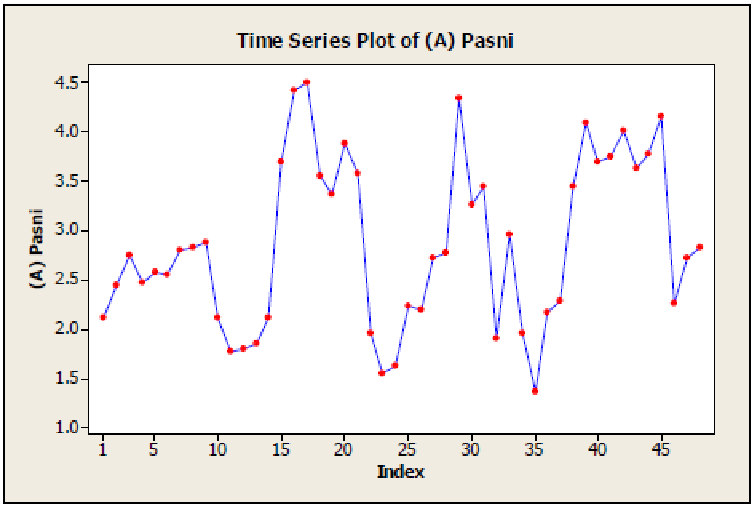

Figure 5.3- Pasni's wind speed time series plot

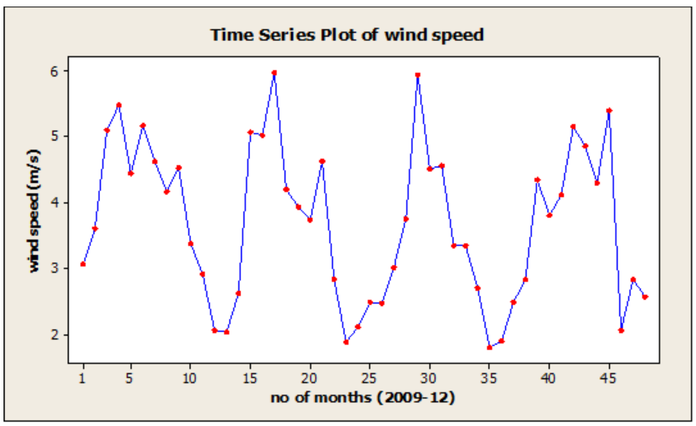

Figure 5.4- Jiwani's wind speed time series plot

5.2 Identification of statistical model

This randomness is checked by computing autocorrelations for values in the data at varying time lags. Autocorrelations near zero indicate randomness in the data. If non-random, then one or more of the autocorrelations will be significantly non-zero. A significant value at lag 1 is seen. Rest of the values are within the 95% confidence band. Autocorrelation functions of the four cities have been shown in Figure 5.5 – 5.8.

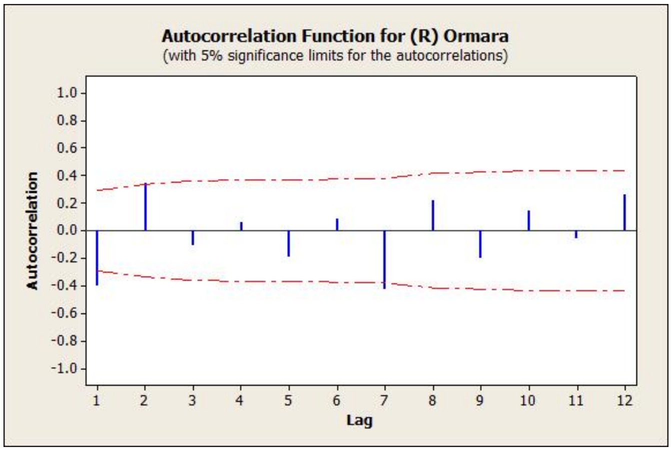

Figure 5.5-Autocorrelation plot for **Ormara**

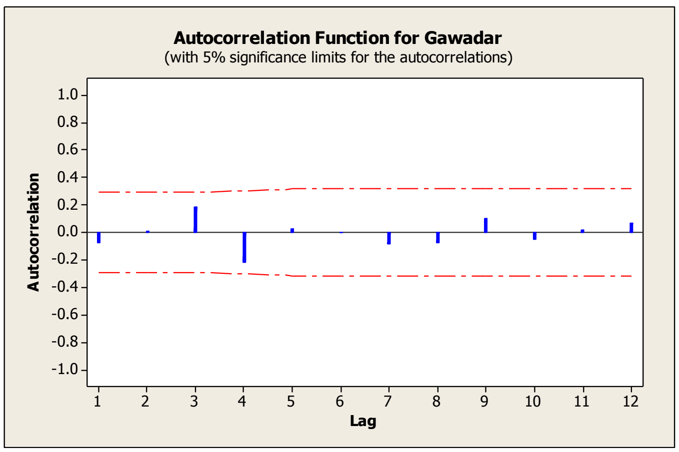

Figure 5.6-Autocorrelation function for **Gwadar**

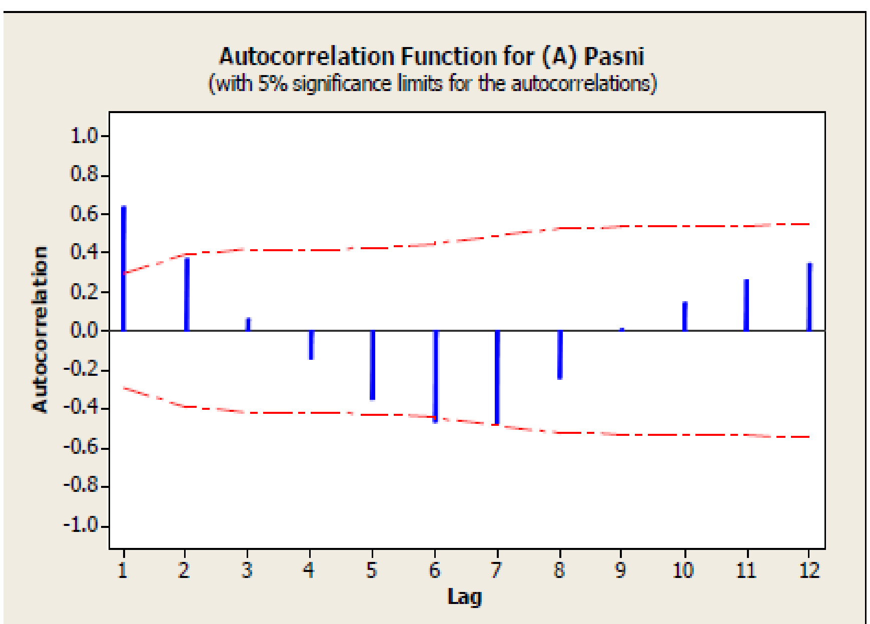

Figure 5.7- Autocorrelation function for **Pasni**

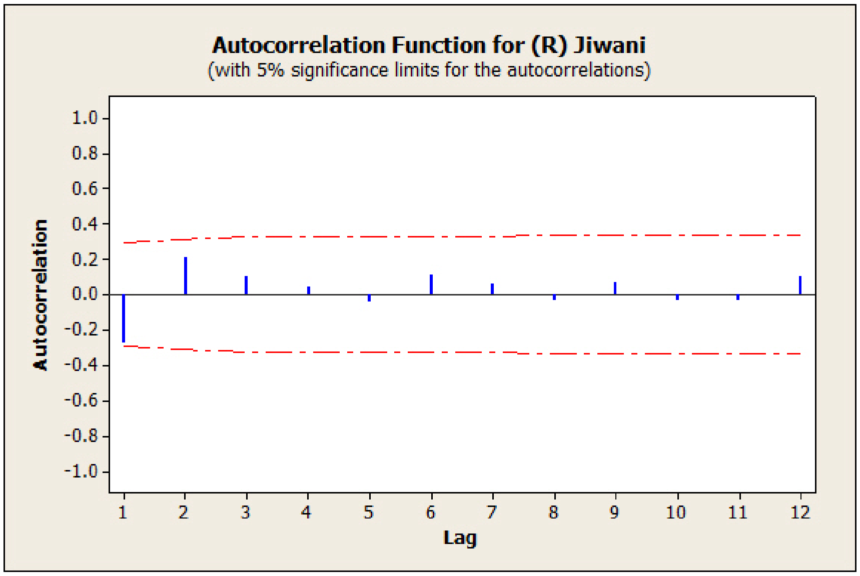

Figure 5.8- Autocorrelation function for **Jiwani**

Partial autocorrelation plot helps identify the model in Box & Jenkins methodology. Partial correlation graph shows significance at lags1 and 7. Rest of the values are in the 95% confidence band. Partial autocorrelation function plots of the four cities are as shown in Figure 5.9- 5.12.

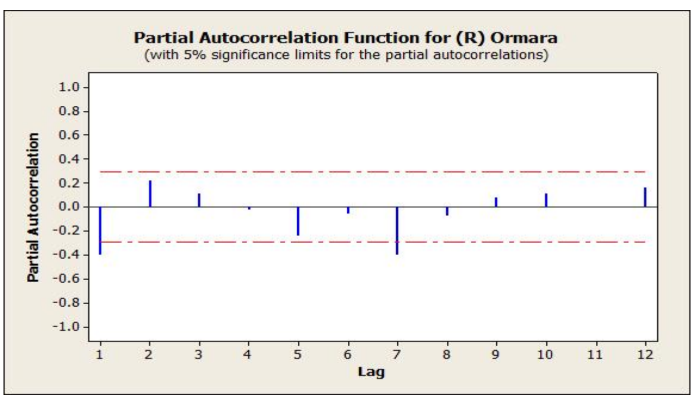

Figure 5.9-Partial Autocorrelation plot for **Ormara**

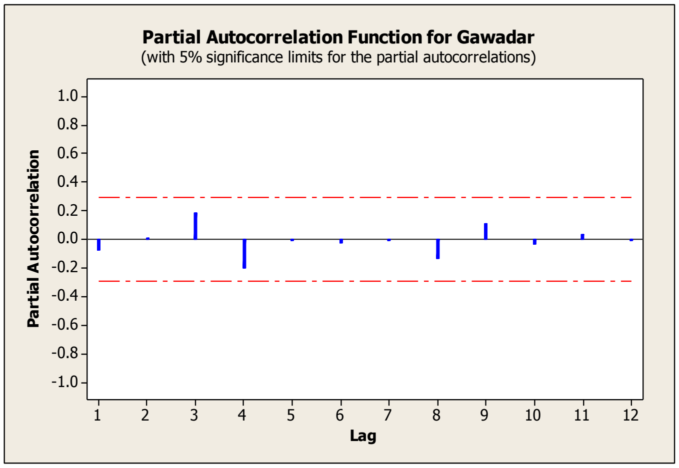

Figure 5.10- Partial autocorrelation function for **Gwadar**

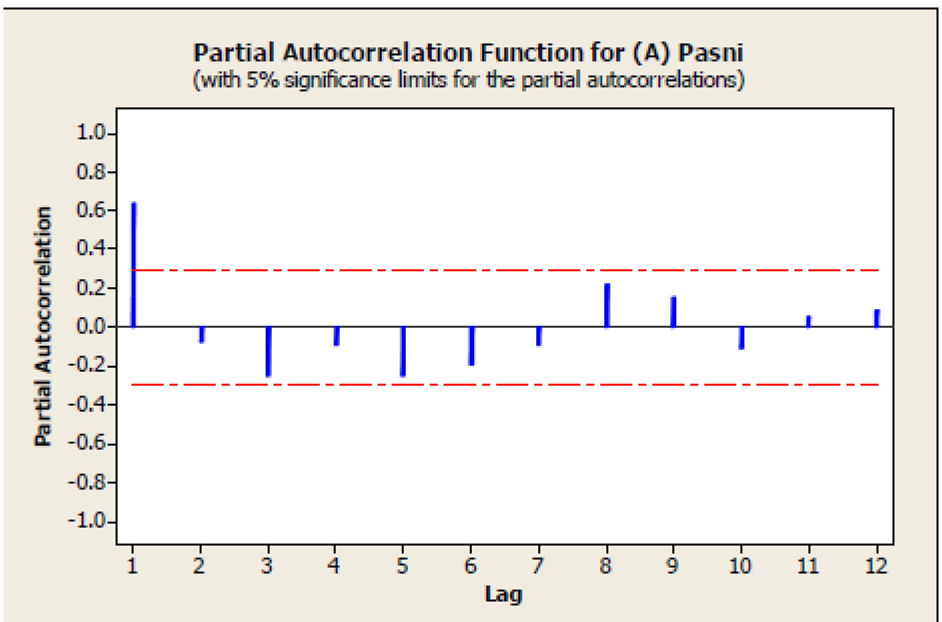

Figure 5.11- Partial autocorrelation function for **Pasni**

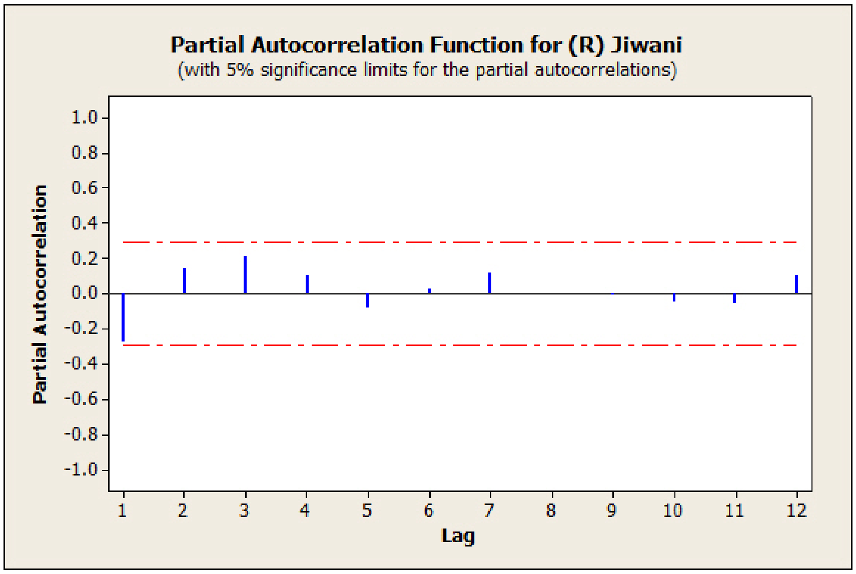

Figure 5.12-Partial autocorrelation function for **Jiwani**

5.3 **Testing**

Normality test is run to check the goodness of fit of a model to the data. A *p* value exceeding 0.05 means that there no white noise error terms and the data has been well modeled. Normality test has been satisfied in this case. Normality tests for the four cities have been shown in Figure 5.13 – 5.16

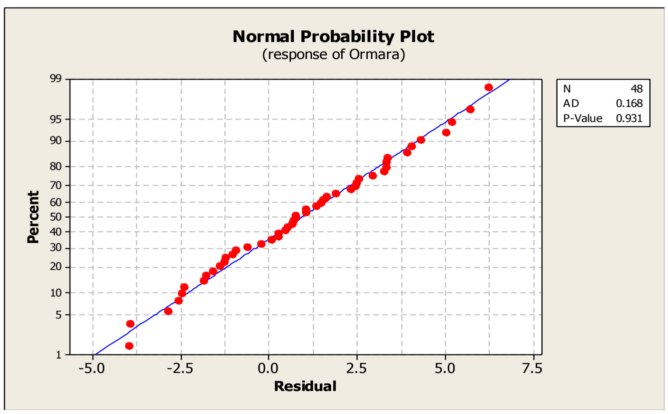

Figure 5.13-Normality test for **Ormara**

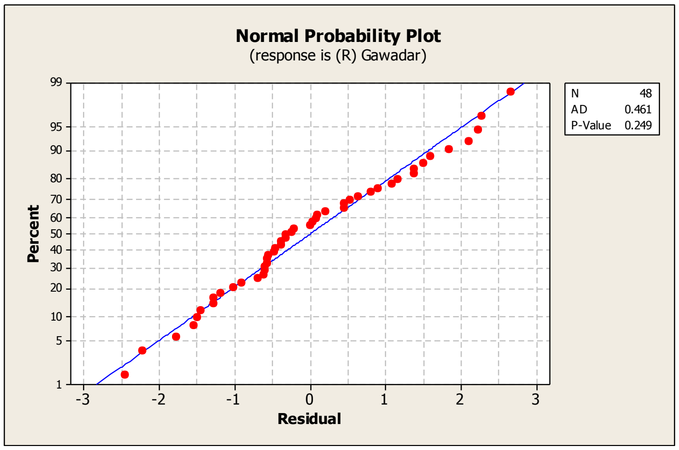

Figure 5.14- Normality test for **Gwadar**

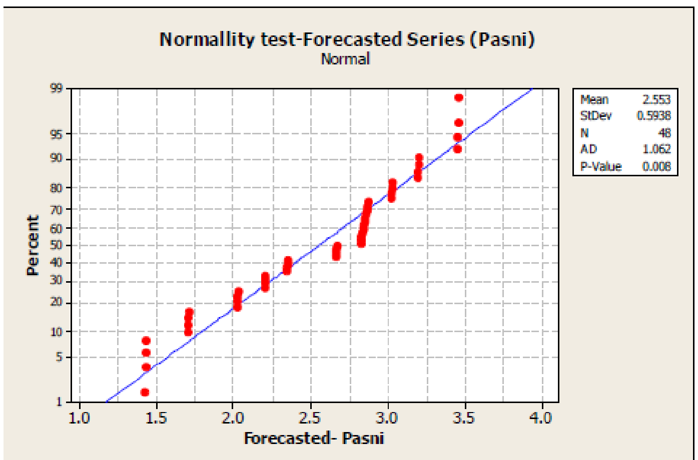

Figure 5.15- Normality test for **Pasni**

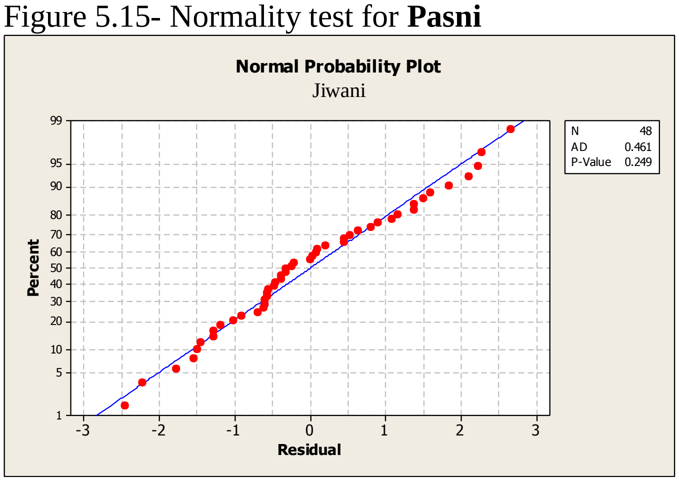

Figure 5.16- Normality test for **Jiwani**

A first-order autoregressive and moving average model-ARIMA (1, 0, 1) was used on the observed series. Its mean forecasted wind speed depends on previous time period value, random value plus moving average of last two terms. The forecasting equation fitted by Statgraphics is:

$$\hat{Y}_t = \mu + \phi_1 Y_{t-1} - \theta_1 e_{t-1}$$

Where $\hat{Y}_t$ represents values in the forecasted series and Y_{t-1} represents the past value in the original series, the last term of the equation $\theta_1 e_{t-1}$ represents white noise and μ is the moving average term. The forecasted series was plotted along with the original series was plotted as shown in Figure 5.5.

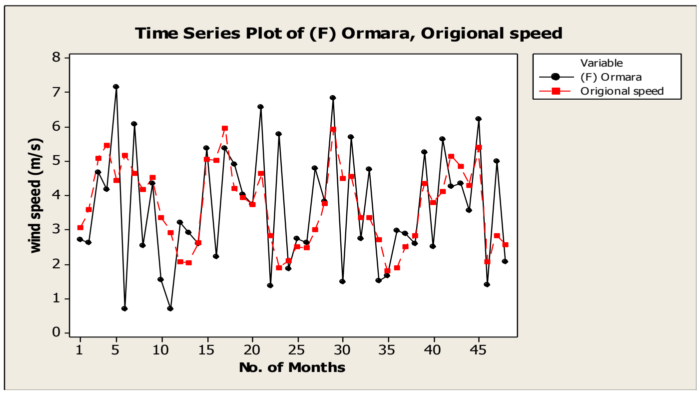

Figure 5.17-Original wind speed series vs ARIMA forecast of **Ormara**

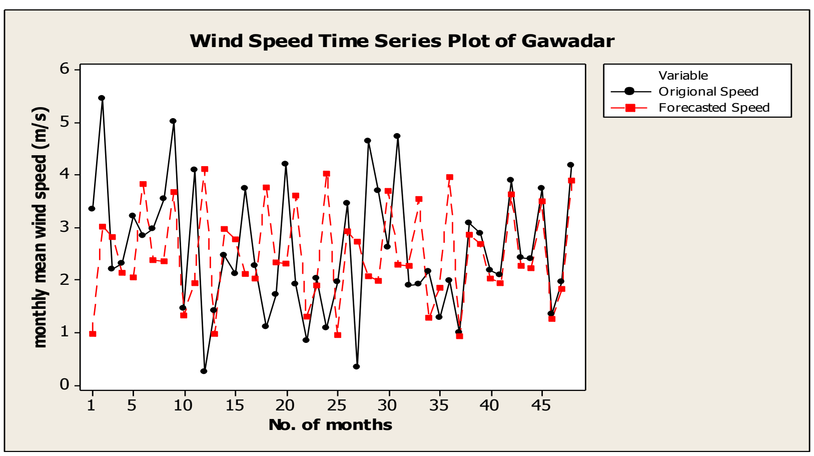

Figure 5.18- Original wind speed series vs ARIMA forecast of **Gwadar**

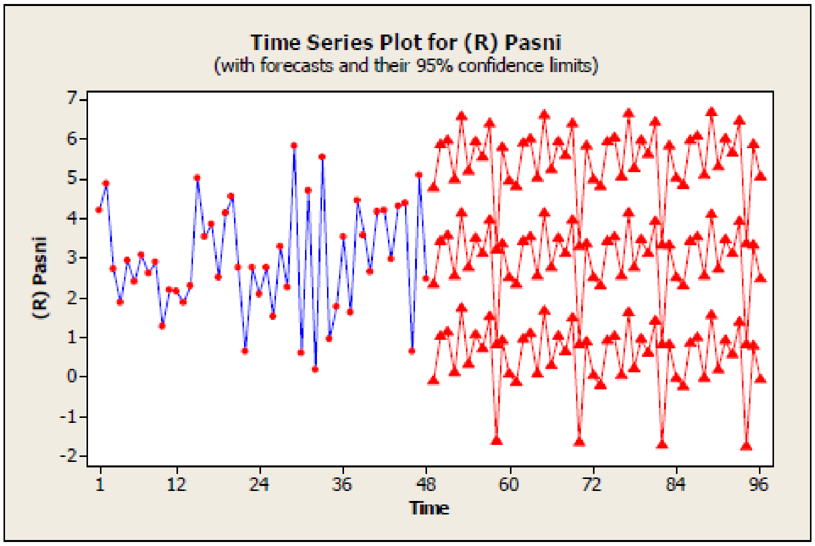

Figure 5.19- Original wind speed time series vs. ARIMA forecast of **Pasni**

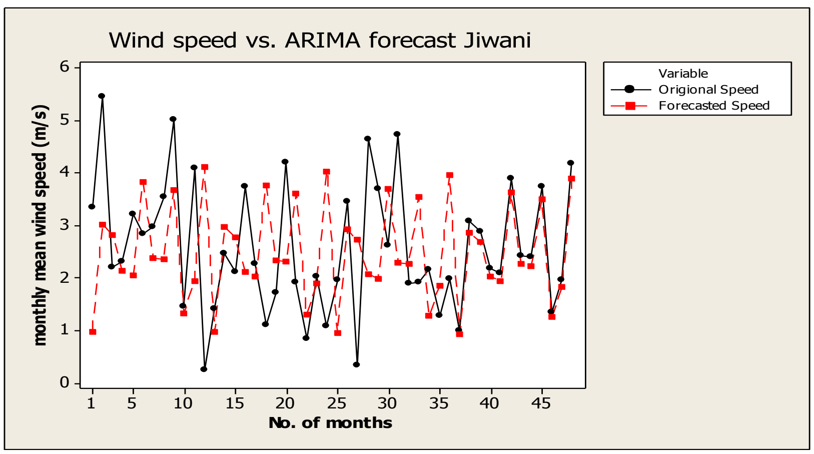

Figure 5.20- Original wind speed time series vs. ARIMA forecast of **Jiwani**

5.4 Artificial Neural Networks

Neural networks are a nonlinear modeling approach which provide an approximation to any function with a fair accuracy. It has been closely associated with the statistical techniques with regards to its applications for model fitting. The prediction model has a generalized form:

$$X_t = f\left(X_{t-1}, X_{t-2}, \ldots., X_{t-p}\right) + e_t$$

With proper designing of the network and parameters, satisfactory performance of the forecasts can be achieved with the help of neural networks. Neural network architectures are properly trained to forecast a particular time series.

Back-propagation Levenberg-Marquardt (BPLM) algorithm for neural networks was used in this study to predict wind speed of the year 2013-2016 for the four cities. The wind speed series obtained from the meteorological observatory was projected to a height of 100m using the wind profile power law. As the previous tests showed that one past value was significant for predicting the series, the lag value was set as 1. The number of hidden neurons were set as 14. Wind speed forecasts for the year 2013-2016 were obtained as shown in figure 5.21- 5.24.

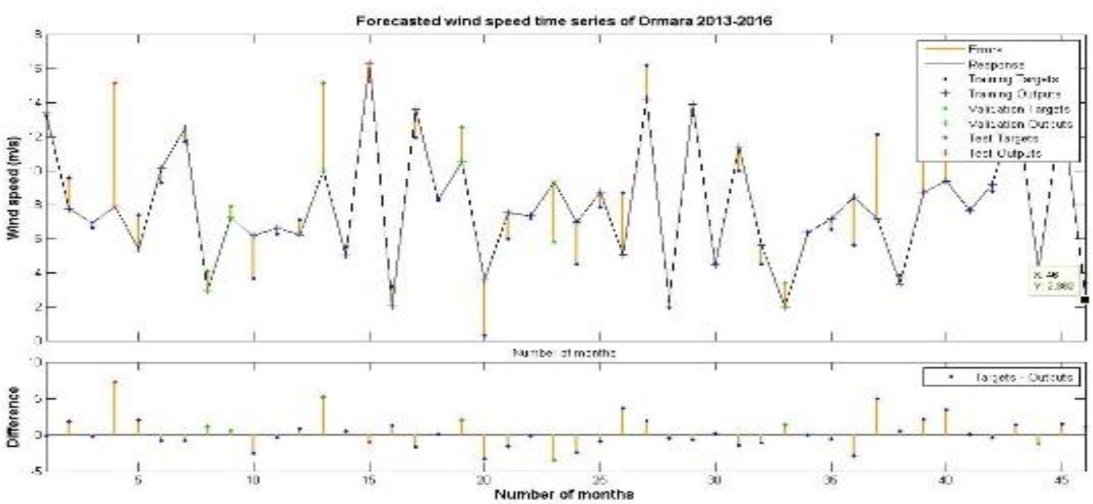

Figure 5.21- Wind speed forecasted series using ANN forecast for **Ormara**

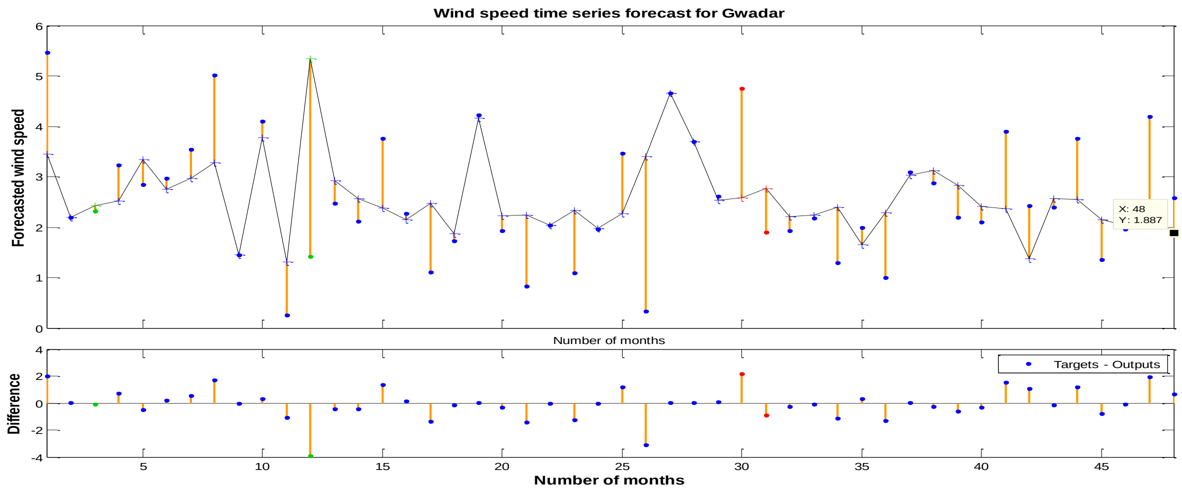

Figure 5.22- Wind speed forecast using ANN for **Gwadar**

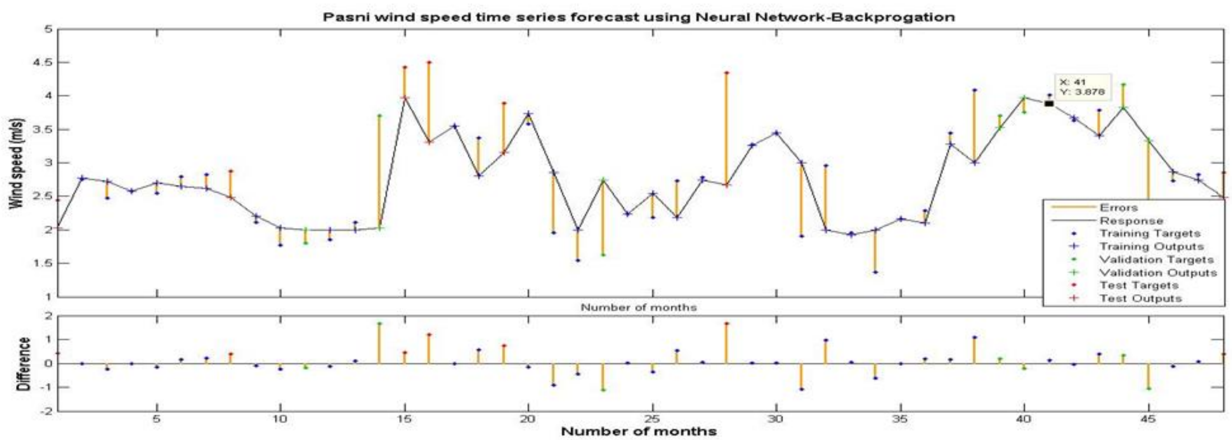

Figure 5.23- Wind speed forecasting using ANN for **Pasni**

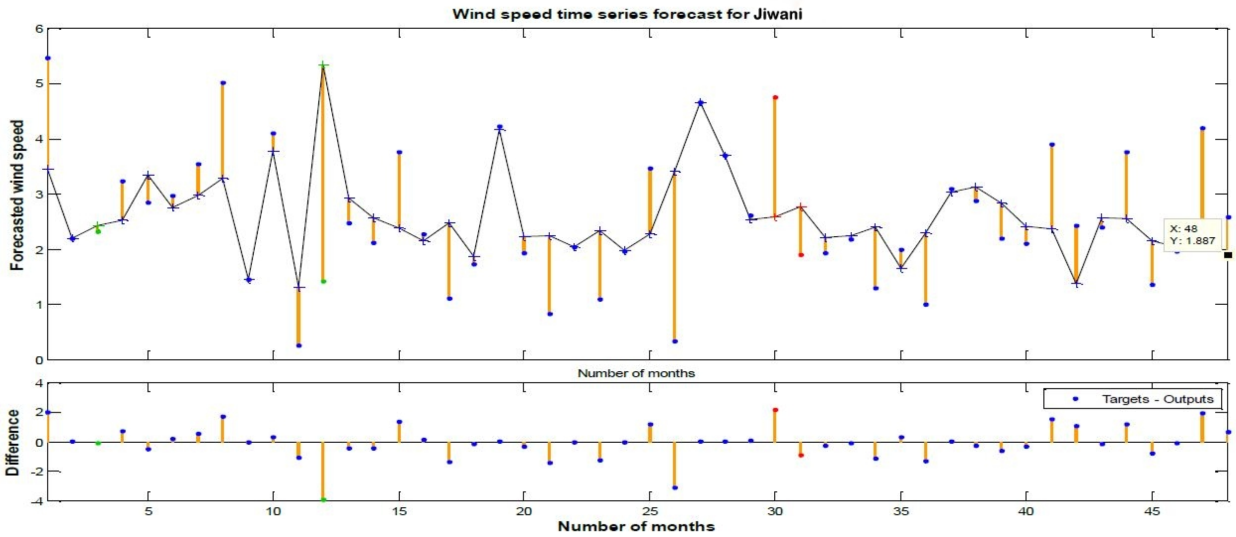

Figure 5.24- Wind speed forecasting using ANN for **Jiwani**

5.5 Comparison

The results obtained from both methodologies i.e. ARIMA and Backpropagation Levenberg-Marquardt algorithm for neural networks were compared. Similarity and consistency in the trend was observed in the forecasted series as shown in Figure 5.25-5.28.

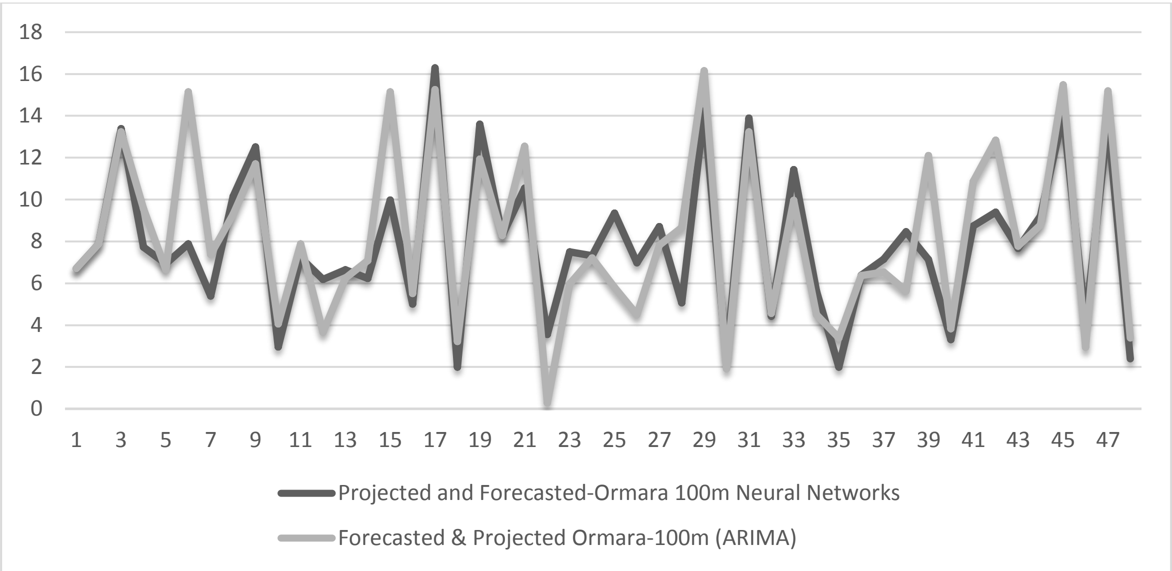

Figure 5.25 -Comparing the ANN and ARIMA forecasts for **Ormara**

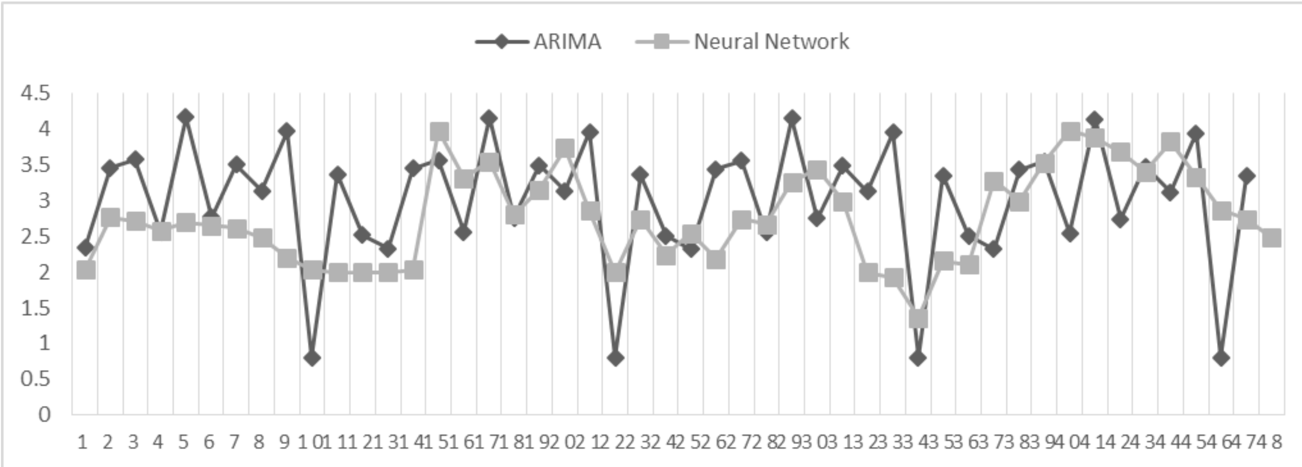

Figure 5.26- Comparing ARIMA and ANN forecasts for **Pasni**

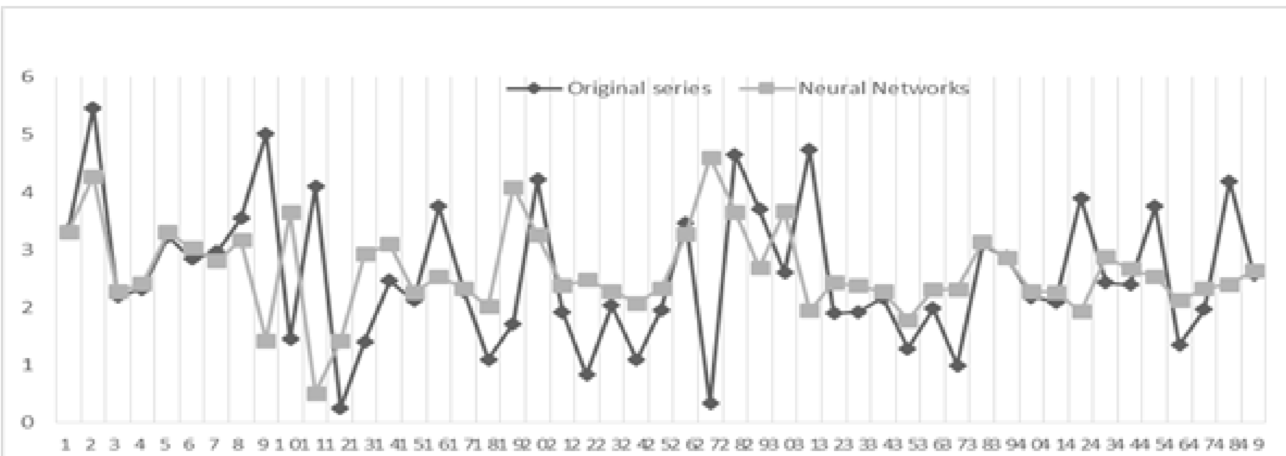

Figure 5.27- Comparing ARIMA and ANN forecasts for **Gwadar**

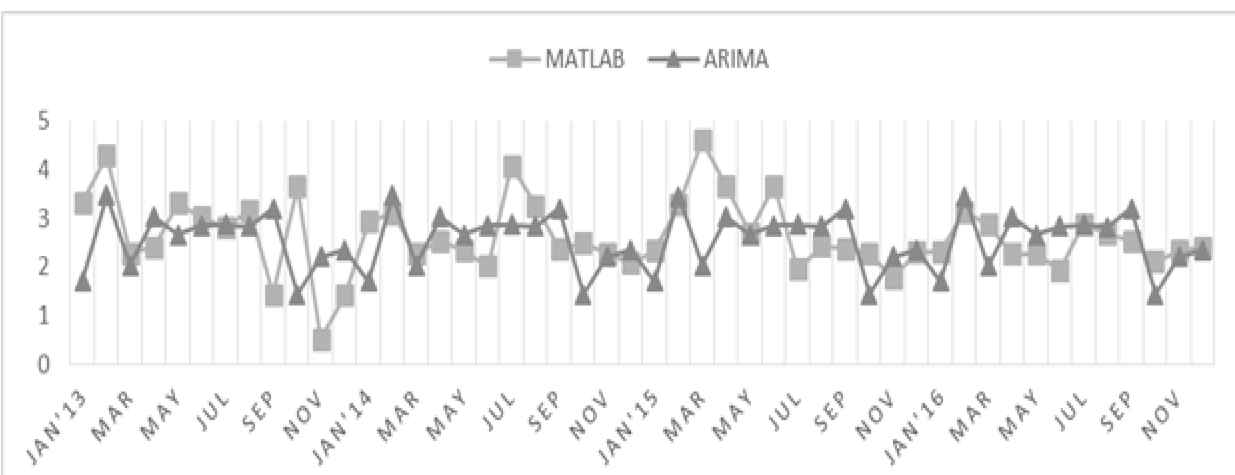

Figure 5.28- Comparing ARIMA and ANN forecasts for **Jiwani**

5.6 **Turbine selection and wind power generation**

For wind power generation, Fuhrlander Wind Turbine with capacity of 3000 kW was chosen after a rigorous testing of different rated turbines on the software RETScreen. To find out the actual power generation, it is necessary to consider the power curve of selected turbine as shown in Figure 5.29.

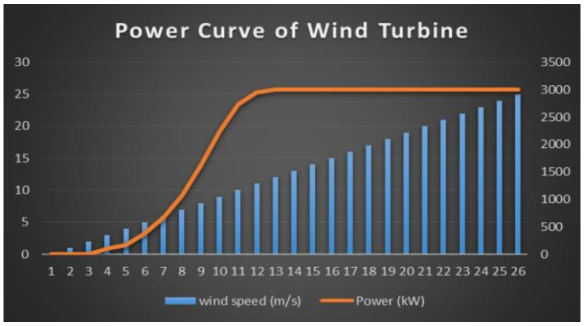

Figure 5.29-Power curve of the Fuhrlander 3MW wind turbine

It indicates how much the wind power can be extracted from wind turbine. It is assessed by an anemometer located at locked to wind turbine in areas with low turbulence intensity.

The selected wind turbine has a cut in speed of 3 m/s and cut out speed of 26 m/s. A wind turbine capture its energy by part of kinetic energy of the wind that goes through swept area of the rotor and convert the force into torque acting on the rotor blades. In the range between the cut in speed and rated speed electric power is generated is a function of cube of wind speed. $P = 0.5\rho A_r C_p \eta V^3$

Where,

ρ = air density 1.184 kg/m^3 at 25^o C

A_r = rotor area

C_p = aerodynamic power coefficient of rotor

η = efficiency of generator i.e. 97%

As wind profile gets smoother and smoother at high altitudes. At 100 m height we get best wind profile so we project forecasted wind speed from 9m into 100 m taking surface roughness 0.20.

α Is called power law exponent. It is dimension less factor. It varies with altitude, time of the daytime, periods of the year, nature of topography. It varies from 0.10 (smooth terrain) to 0.40 (very rough terrain). For our study the value of alpha was set at 0.2.

Case Study

A hypothetical case study was done for the four cities of Balochistan. The investment cost is 126.735 million US$. It includes EPC cost, Non-EPC cost, Interest during Constructions (IDC). The parameters that were chosen for the study are mentioned in Table 5.1. Paramters were chosen by studying the successfully implemented projects of Zorlu energy wind farm and three gorges wind farms in Jhimpir, Sindh.

Table 5.1- Parameters chosen for case study for the coastal areas of

Parameters	Units	Value
Technical Data		
Study date	-	2015
Useful life	Years	20
Fuhrlander Wind Turbine	MW	3
No. of turbines		17
Swept area of turbine	m^2	11,423
Installed Capacity	MW	50
Investment		
Total Project Cost	US$ Million	126.735
EPC Cost	US$ Million	115.166
Non EPC Cost	US$ Million	11.569
Losses		
Array Losses		5%

Airfoil Losses		2%
Miscellaneous losses		2%
Turbine Availability		95%

Without considering the wind speed uncertainty, financial analysis is performed and results for Ormara, Gwadar, Pasni and Jiwani are given in Table 5.2-5.5 respectively.

Table 5.2-Financial Analysis for **Ormara**

Benefit Cost Ratio (B.C.R)	1.22
Payback Period	5 years
Internal Rate of Return (I.R.R)	18%
Sensitivity Analysis	
10% prices increase (I.R.R)	15%
10% prices decrease (I.R.R)	20%

Table 5.3- Financial analysis for **Gwadar**

Benefit Cost Ratio (B.C.R)	1.04
Payback Period	9 years
Internal Rate of Return (I.R.R)	11%
Sensitivity Analysis	
10% prices increase (I.R.R)	9%
10% prices decrease (I.R.R)	13%

Table 5.4- Financial analysis for **Pasni**

Benefit Cost Ratio (B.C.R)	0.43
Payback Period	14.5 years
Internal Rate of Return (I.R.R)	6%

Table 5.5- Financial analysis for **Jiwani**

Benefit Cost Ratio (B.C.R)	0.62
Payback Period	11 years
Internal Rate of Return (I.R.R)	8%

Summary

The analysis done in this study through ARIMA and neural network BPLM models indicates both neural network and ARIMA provided similar forecasts with and performed the forecast of the time series with similar accuracy. Increasing the height from the optimum value results in increase in costs without any considerable increase in power output and decreasing the height from the optimum value results in significant decrease in performance. The optimum wind height according to present study is 100m and the optimum wind turbine is Fuhrlander's 3MW turbine. The forecasted wind speeds have mean absolute percentage error of 12.984%. From investor's viewpoint it is profitable to invest in wind farm projects at Ormara according to the financial analysis. However, Pasni was found to be the least profitable so it is not advisable to invest in Pasni while Jiwani and Gwadar are average sites for this kind of investment.

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Chapter 6: Wind-thermal storage system

The main tasks of storage are buffering during transient weather conditions, dispatch ability, improving the annual capacity factor of the power plant, even distribution of electricity and achieving full load operation of the steam cycle at high efficiency. On the other hand the major requirements of storage system are high energy density of the storage material, good heat transfer between heat transfer fluid and the storage medium, mechanical and chemical stability of storage material, chemical compatibility of heat transfer fluid, heat exchanger and storage medium, reversibility of charging/ discharging cycles, low thermal losses and ease of control. There are various approaches to achieve storage of power. In this study, thermal energy storage have been discussed.

6.1 Thermal energy storage types

Recent studies have shown that thermal energy systems are cost effective and efficient for concentrated solar power plants. The cost of the overall system is reduced and the availability of the solar power is considerably improved with TES [1][2]. The three main approaches for thermal energy storage are *sensible heat storage, latent heat storage* of phase change materials (PCM) and *thermochemical storage* by reversible chemical reactions [1]. The sensible heat storage, a storage medium is used which is one and the same as the liquid heat transfer fluid in either or both of the two flow loops. The simultaneous collection, transfer and storage of heat is termed *direct thermal storage*. On the other hand, *indirect thermal storage system* involves a separate storage medium from the collector heat transfer fluid, incorporating some form of heat exchange arrangement [1].

Solar Energy Generating Systems (SEGS) in California, with the combined capacity from three separate locations at 354 MW is the second largest solar thermal energy facility in the world. The SEGS-1 facility employs two-tank mineral oil storage system with a capacity of 115MWh [2].

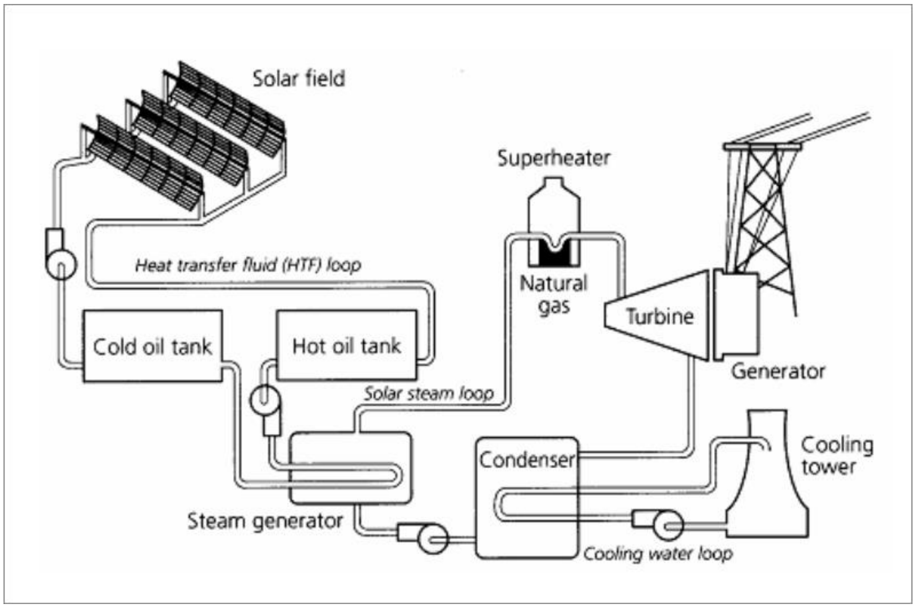


Figure 6.1- Process Scheme of SEGS-1 [2]

SEGS also uses a two tank molten salt storage at one of its facilities as shown in Fig. 6.2 that uses a nitrate salt mixture which acts as storage and also as the heat transfer fluid. This system has a capacity of 105MWh [2][3].

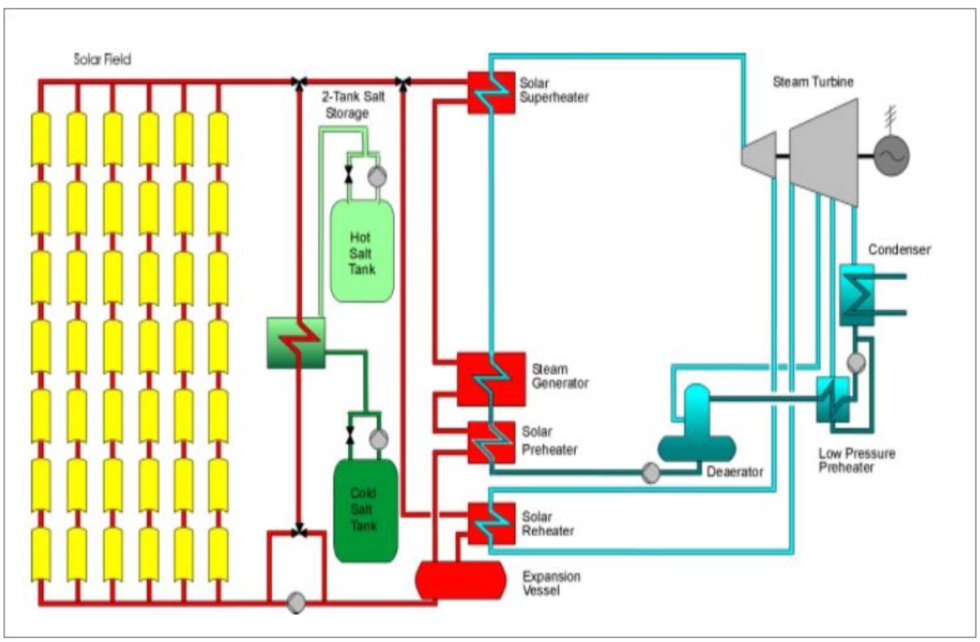


Figure 6.2 -Process scheme of SEGS molten salt storage system [2]

Phase change materials (PCM) have also been frequently discussed for thermal energy storage. These materials store heat associated with phase transition. The amount of heat stored in these materials is proportional to the material mass, the fraction of material that undergoes the phase change, and the material heat of fusion [1]. Since the phase-transition enthalpy of PCMs are usually much higher (100- 200 times) than sensible heat, latent heat storage has much higher storage density than sensible heat storage. However, the main disadvantage of latent heat stor- age is its low thermal conductivities, which mostly fall into the range of 0.2 W/(m K) to 0.7 W/(m K), and therefore relative heat transfer enhancement technologies must be adopted [4]. Luz International Ltd. after completion of SEGS (I-V) highlighted the need for advanced, cost-effective and reliable technologies to fully utilize the high operating temperature of the solar field (397 degree Celsius). In seeking a solution to this need, Luz developed two conceptual designs of TES systems utilizing phase change materials in the temperature range of interest for a SEGS plant [5].

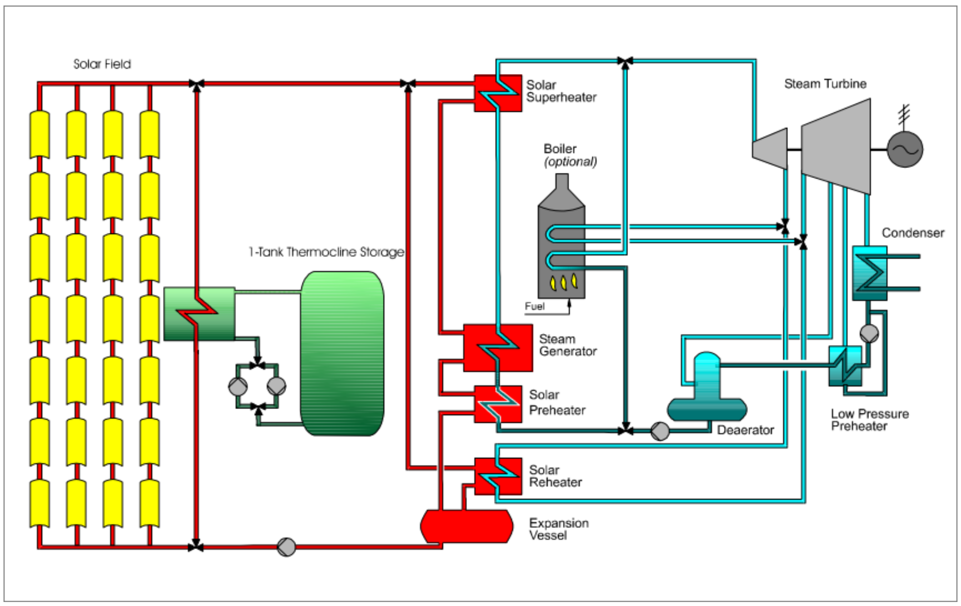


Figure 6.3 -Process Scheme for SEGS for PCM storage [2]

Special chemicals can absorb/release a large amount of thermal energy when they break/form certain chemical bonds during endo- thermal/exothermal reactions. Based on such characteristics, the storage method making use of chemical heat has been invented. Suitable materials for chemical heat storage can be organic or inorganic, as long as their reversible chemical reactions involve absorbing/releasing a large amount of heat. When designing a chemical storage system, three basic criteria need to be considered:

excellent chemical reversibility, large chemical enthalpy change and simple reaction conditions [4].

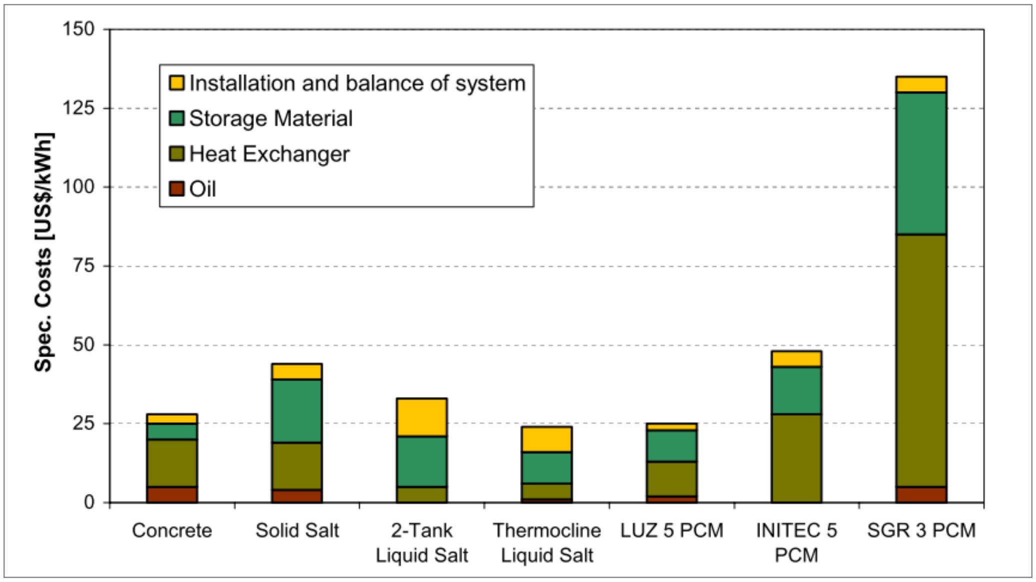


Figure 6.4- Specific costs of different thermal energy storage systems [2]

Three storage options offer favorable cost are two tank molten salt storage or one tank salt storage thermocline, concrete storage and phase change material [2].

By all existing research studies, it has been proved that thermal energy storage is a cost effective way of storing energy for intermittent power sources. Since wind power is highly intermittent, backup thermal storage systems deserve attention. The energy costs of the wind with backup thermal, the wind with battery energy storage and Wind Powered Thermal Energy System (WTES), which employs heat generator and thermal energy storage system were compared by Okazaki et. al. It seems WTES becomes the most economical system in these three systems although the estimation is in its initial stages. WTES becomes much more attractive when it is constructed besides CSP and/or bio-mass plant since many parts of elements can be shared [6]. Siemens and Apple have also shown interest in the development of a similar wind thermal energy systems[7][8].

6.2 Overview of the system

A thermal energy storage system mainly consists of three parts, the storage medium, heat transfer mechanism and containment system. The thermal energy storage system modeled in this work uses the two-tank-direct configuration where the heat transfer fluid (HTF) also acts as the energy storage medium. This requires two separate tanks, but eliminates the need for an additional heat exchanger to transfer heat from the collection HTF to the storage medium. The fluid is stored at its lower temperature in a cold tank, heated by mechanical work from wind turbine, and then stored at an elevated temperature in the hot tank. The stored energy in the hot tank is delivered to the load by pumping the HTF through the boiler. In this model, it is assumed that saturated liquid water is fed to the boiler and it exits as saturated steam. In this exchange, the HTF returns to its lower temperature and is pumped back to the cold tank. The output power is represented by the flow rate of the saturated steam generated in the boiler [9].

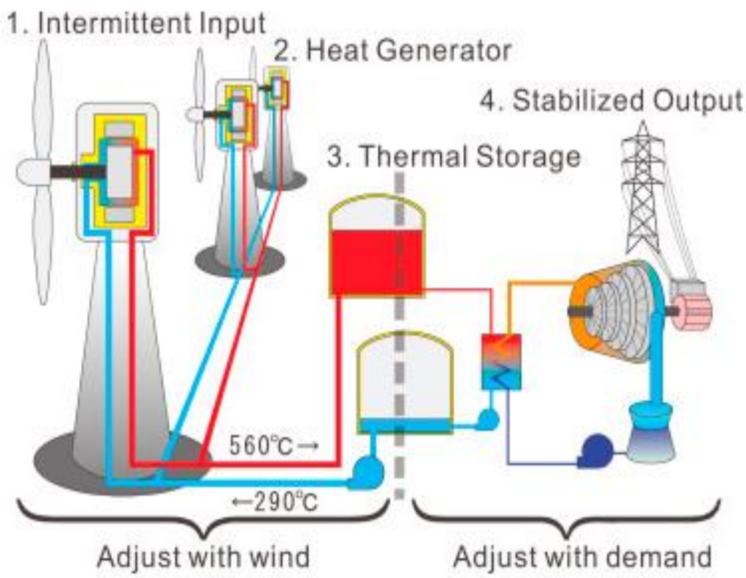


Figure 6.5 -Wind Thermal Energy System using two tank molten salt technology [6]

6.3 Modelling WTES

In a wind turbine, the kinetic energy in the wind turns the propeller-like blades around a rotor. The rotor is connected to the main shaft, which spins a generator to create electricity. The maximum theoretical value of the coefficient of performance is 0.593, a value determined by a fluid mechanics constraint known as the Betz limit. Actual coefficients of performance are less than this limit due to various aerodynamic and mechanical losses. The performance coefficient Cp of the turbine is the mechanical output power of the turbine divided by wind power and a function of wind speed, rotational speed, and pitch angle (beta).

However, the concept used in this study is to use the mechanical work of the rotor instead of converting it into electricity. The rotating energy is converted to the thermal energy at the top of the tower directly. This thermal energy can be stored as sensible heat in the thermal energy storage system. The stored thermal energy is transferred by the heat transfer fluid (HTF) to produce steam that drives the turbine generator when required [6].

$$Power\ by\ the\ wind = P = \frac{\rho A v^3}{2}$$

Where, ρ is the density of air, A is the cross-sectional area, v is the velocity of the wind

$$Power\ by\ the\ blade = P_b = P_w \times C_p$$

C_p is the performance coefficient determined by Betz limit

$$Tip\ speed\ ratio = \lambda = \omega R/v$$

Where ω is the rotational speed, R is the length of the blade, v is the velocity of the wind. Solving for rotational speed,

$$\omega = \frac{\lambda v}{R}$$

By calculating rotational velocity, torque and work done can be determined.

$$Torque = \tau_r = \frac{P_b}{\omega}$$

$$W=\tau_r \theta = I\alpha\, \omega^2$$

$$W = \frac{1}{2} I\, \omega^2$$

Where θ is the rotation by the shaft, I is the moment of inertia. Moment of inertia for three cylindrical blades is given by:

$I = 3\ (\frac{1}{3} ML^2) = ML^2$

Finally work is given by, W= $ML^2\ \omega^2$

For simplicity the shape of the turbine blade has been considered a cylindrical rod. The actual shape of the blade is complex and varies among different manufacturers.

Next step is to convert mechanical work into heat. This can be accomplished using a heat generator. The heat generator has lighter weight and lower cost than that of the electric generator since the heat generator is a kind of simple brake in principle [6]. The mechanical equivalent of heat states that motion and heat are mutually interchangeable and that in every case, a given amount of work would generate the same amount of heat, provided the work done is totally converted to heat energy. By first law of thermodynamics, $\Delta U = Q + W$. For no change in internal energy, all the work done on a system will be converted to heat.

The heat generated can be then moved to the base utility for molten salt storage. There might be some heat losses during the transfer which have not been taken into consideration for this study. A molten salt mixture of nitrates 60 % $NaNO_3$ 40% KNO_3 with a melting point of 221^oC was chosen. The temperature of both tanks at all times should be above the melting point to avoid solidification. The molten salt acts as heat transfer fluid (HTF) to heat liquid water to steam which then drives a steam turbine to generate electricity.

In the current model, a three blade horizontal axis wind turbine was modeled for wind speed near Columbia River gorge, Oregon, US for a hub height of 100m. The input wind speed to the model is as shown in Fig.7. For a co-efficient performance of 0.4, blade length of 37m and density of air 1.2041kg/m^3, the output power of such a turbine would be varying with the cube of winds speed and therefore highly variable. This intermittency creates problems of stability and power scheduling in the grid. Ideally, using thermal storage system the output power should be a constant number, storing the energy during peak wind speeds and delivering the stored energy during the less windy durations.

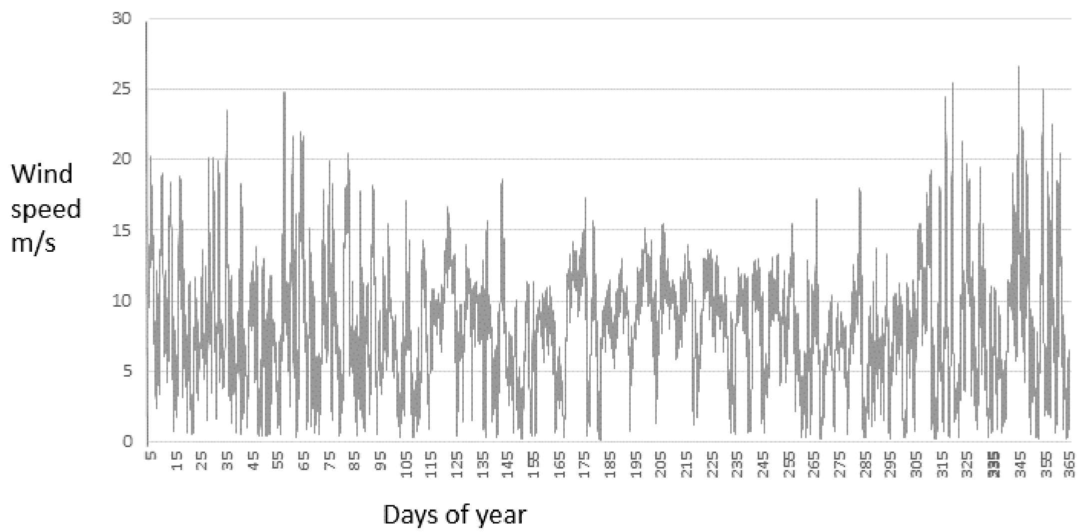


Figure 6.6- Wind speed time series for the year 2006 in Oregon, US at 100m height

The ratio of the tangential speed of the blade tip and wind velocity is given by tip speed ratio (TSR). This varies with material, structure and design of the blade. If the tip speed ratio is too high, the blades of the turbine are moving too fast and acting like solid wall against the wind. Alternatively, if the tip speed ratio is too low, the blades are moving too slow and the wind is passing without being utilised. Tip speed ratio is chosen such that the blades do not pass through turbulent air while efficiently capturing the non-turbulent winds. A well designed rotor would have a tip speed ratio of 6 to 7. Co-efficient of performance C_p used in the wind power calculation is still relevant since the turbine losses and mechanical losses need to be accounted for.

Overall turbine efficiency, $C_{p=} \eta_a \times \eta_m \times \eta_e$

Where η_a= efficiency of turbine (blade aerodynamic efficiency), η_m= mechanical efficiency taking into account the power lost to bearing and gear tooth friction and η_e= electrical efficiency accounting for power lost to windings and electrical resistance

Since, in this study we are not using the generator part of the turbine electrical efficiency does not need to be accounted for. Therefore, $C_{p=} \eta_t \times \eta_m$

Theoretically, by using the principles of brake or exerting work on molten salt storage tank (stirring) all of the work done can be converted to heat. The heat generated in Joules is shown in Fig. 8.

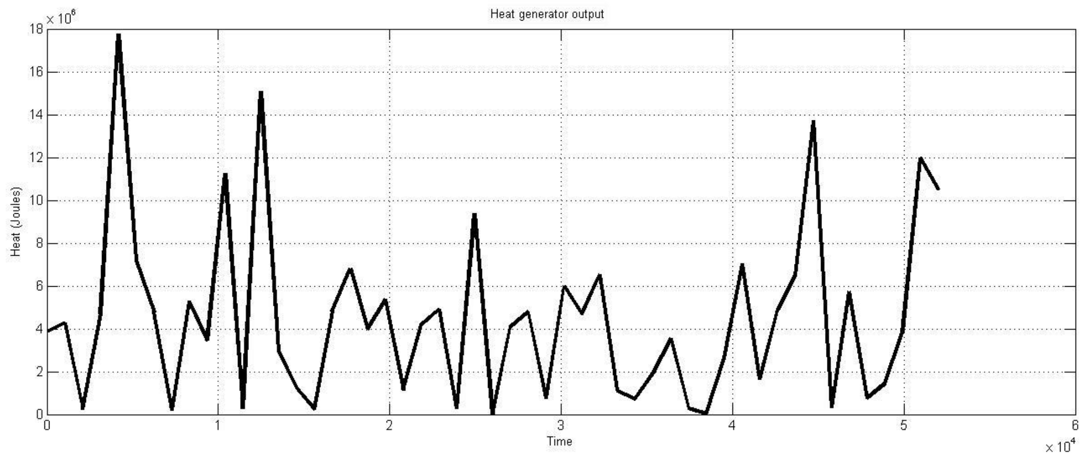


Figure 6.7- Heat generated by the heat generator in joules in an year

The volume of the salt plays an important role in determining the temperature of the molten salt. For this model, the volume was kept at $7m^3$ to raise the temperature of the molten salts from 265°C (538.15 K) to 551.85°C (825K). This volume and temperature have been adjusted according to the existing technology and to exchange enough heat from the molten salt to run the steam turbine and avoid condensation inside the steam turbine. The temperature of the hot tank of molten salt is shown in Fig. 9

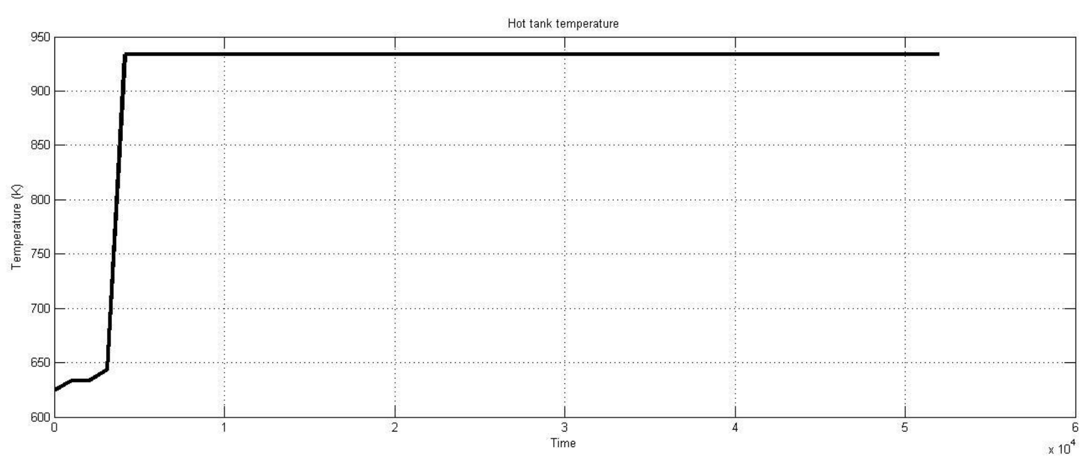


Figure 6.8- Maximum temperature achieved in the thermal storage hot tank

The high efficiency of molten salt storage systems ensure minimum losses of energy at this step. The thermal energy stored Q depends upon the volume of the tank V, heat capacity of the salts c_p and temperature difference dT between the two tanks. $Q = \rho_s V c_p dT$. Salt slurry must be easy to pump and heat transfer coefficient must exceed 150 W/m^2K for the system to function. Lesser the heat- coefficient, larger the size of required heat exchanger. Log mean temperature difference was calculated for the heat exchanger using the temperature of the hot tank for heating the water from 25 ^oC to 312 ^oC. The parameters of molten salt and heat exchanger have been listed in Table 6.1.

Table 6.1- Selected parameters of molten salt tank storage and heat exchanger

Heat capacity of nitrate salts	1.6 kJ/kg K
Cold tank temperature	538 K
Density of salts	1870 kg/m^3
Heat transfer co-efficient	355 W/m^2K
Area of heat exchanger	40 m^2
Mass flow rate	12,600 kg/hour

Counter flow heat exchanger was chosen for this model as shown in Fig.6.9

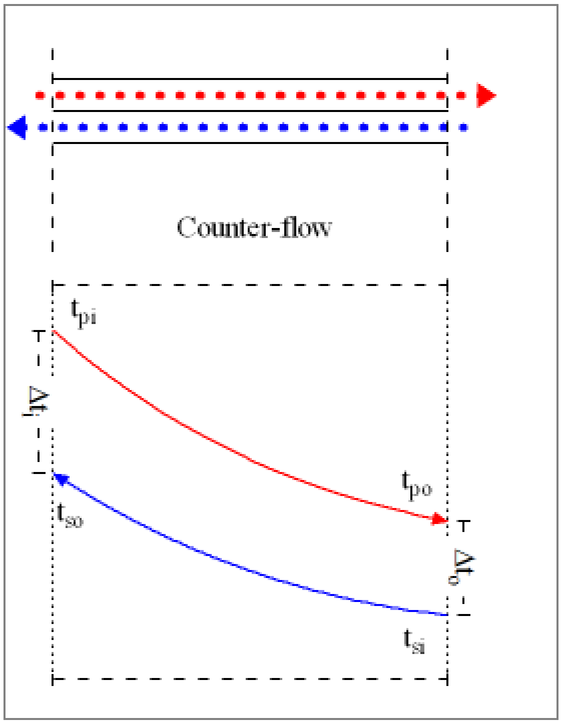


Figure 6.9- Counter flow configuration of heat exchangers

Heat rate oh heat exchanger was determined as shown in Fig.6.10.

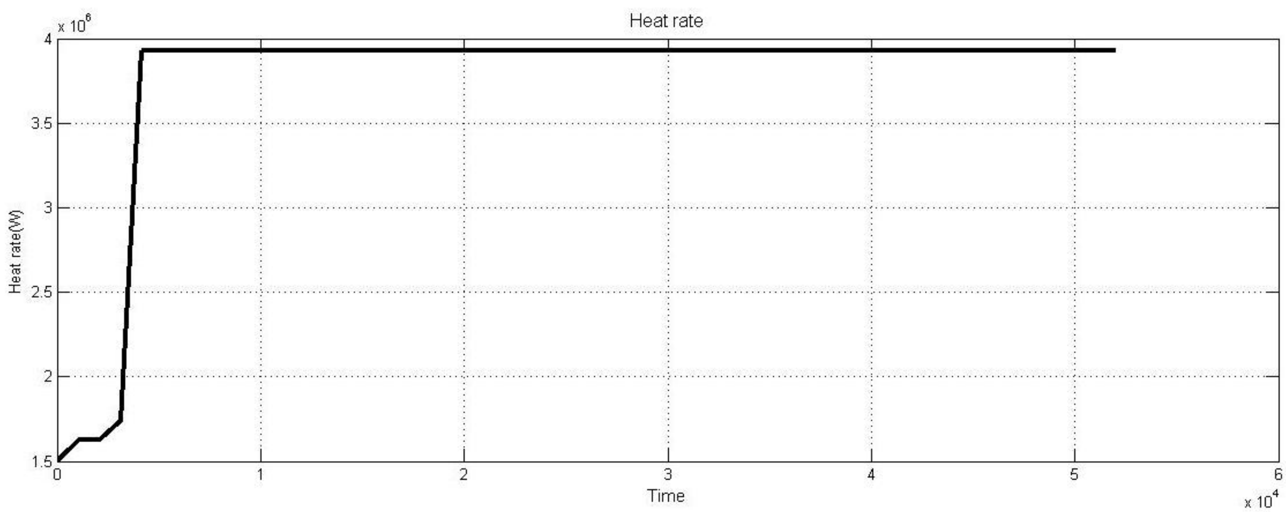


Figure 6.10- Heat rate by the heat exchanger

Mass flow rate was determined as 3.2 kg/s or 12,600 kg/hour required for optimum output from steam turbine

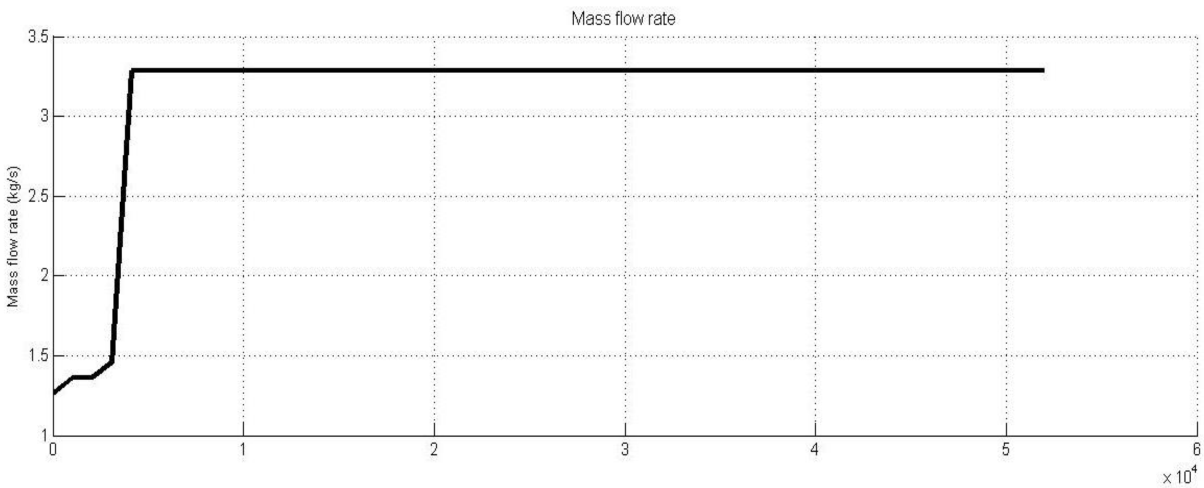


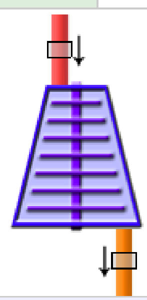
Figure 6.11-Mass flow rate of water

Using the steam system modeller tool SSMT by US department of energy [10], the steam turbine was modeled. The following parameters of the steam turbine were set to ensure optimised functioning and no condensation in the turbine.

Table 6.2- Steam turbine model

Solve for:	
Outlet Properties ▼	
Inlet Steam	
Pressure*	1000 *psig*
Temperature ▼ *	900 *K*
Turbine Properties	
Selected Turbine Property	Mass Flow ▼
Mass Flow *	12600 *kg/hr*
Isentropic Efficiency *	80 %
Generator Efficiency *	95 %
Outlet Steam	
Pressure*	100 *psig*
** Required*	Enter [reset]

Inlet Steam		Mass Flow	12,600 *kg/hr*
Pressure	1,000.0 *psig*	Sp. Enthalpy	3,714.4 *kJ/kg*
Temperature	900.0 *K*	Sp. Entropy	7.163 *kJ/kg/K*
Phase	Gas	Energy Flow	46,802 *MJ/hr*



Isentropic Efficiency	80.0 %
Energy Out	7,062 *MJ/hr*
Generator Efficiency	95.0 %
Power Out	1,863.6 *kW*

Outlet Steam		Mass Flow	12,600 *kg/hr*
Pressure	100.0 *psig*	Sp. Enthalpy	3,153.9 *kJ/kg*
Temperature	619.2 *K*	Sp. Entropy	7.403 *kJ/kg/K*
Phase	Gas	Energy Flow	39,740 *MJ/hr*

$$Inlet\ energy\ flow = specific\ enthalpy \times mass\ flow$$

$\dot{\epsilon}_i = h_i \dot{m}_r$ = 2,984.6 kJ/kg * 12,600 kg/hr = 46,802 MJ/hr

$$Isentropic\ efficiency$$

$$= (\frac{(inlet\ specific\ enthalpy - outlet\ specific\ enthalpy)}{inlet\ specific\ enthalpy - ideal\ outlet\ specific\ enthalpy)}$$

$$\eta_{is} = \frac{h_i - h_o}{h_i - h_{ideal}}$$

$$Outlet\ specific\ enthalpy$$

$$= inlet\ specific\ enthalpy - isentropic\ efficiency$$

$$\times (inlet\ specific\ enthalpy - ideal\ outlet\ specific\ enthalpy)$$

$$h_o = (h_i - \eta_{is})(h_i - h_{ideal})$$

= 3714.4 kJ/kg – 0.80 * (3714.4 kJ/kg - 2,758.6 kJ/kg)]

= 3,153.9 kJ/kg

Assumptions: Inlet mass flow is equal to equal outlet mass flow.

$$Energy\ out = (inlet\ specific\ enthalpy - outlet\ specific\ enthalpy)$$

$$\times mass\ flow$$

$$\dot{\epsilon}_o = (h_i - h_o)m_r$$

= 7,062 MJ/hr

$$\text{Power output} = \text{energy out} \times \text{generator efficiency}$$

$$P_0 = \dot{\epsilon}_o \times \eta_{gen}$$

Power output = 1836.6kW

The output steam temperature is 619.2K which is enough to generate another 900 kW using the same system and re-pressurizing the outlet steam.

6.4 Overall efficiency of the system

Since we know the efficiency of the steam turbine (isentropic efficiency and generator efficiency), yet to be determined is the efficiency of the heat exchanger.

Efficiency of heat exchanger:

T = hot fluid temperature

$$t = cold\ fluid\ temperature$$

$$\bar{T}\ ? = average\ temperature\ of\ the\ hot\ fluid\ T$$

$$\bar{t}\ ? = average\ temperature\ of\ the\ cold\ fluid$$

$$NTU = number\ of\ transfer\ units$$

U = overall heat transfer coefficient, W/m^2 K

$$Cr = capacity\ ratio\ Cr = Cmin/Cmax$$

$$A = heat\ exchanger\ surface\ area, m2$$

$$Heat\ capacity\ rate\ of\ the\ cold\ fluid = Cc = (\dot{m}\, c_p)_c$$

$$rate\ of\ heat\ transfer = q = Cc\,(t2 - t1)$$

$$Heat\ capacity\ rate\ of\ the\ hot\ fluid = Ch = \frac{q}{T_2 - T_1}$$

$$q = UA\,(\bar{T} - \bar{t}\,) = \eta\, Cmin\, NTU\,(\bar{T} - \bar{t}\,)$$

$$NTU\,\eta = q\ /\ Cmin\,(\bar{T} - \bar{t}\,)$$

$$\eta = \tanh NTU \frac{\sqrt{1+C_r{}^2}}{2} \Bigg/ NTU\ \frac{\sqrt{1+C_r{}^2}}{2})$$

Efficiency of the heat exchanger can be calculated using the above equations. For this model, the efficiency is 0.9.

$$Overall\ efficiency\ of\ the\ system$$
$$= (Eff.of\ the\ wind\ turbine\ and\ rotor)$$
$$* (Eff.of\ heat\ generator) * (Eff.of\ TES)$$
$$* (Eff.of\ heat\ exchanger) * (Isentropic\ eff.)$$
$$* (Generator\ eff.)$$

η' = $C_{p} \times \eta_{hg} \times \eta_{TES} \times \eta_{he} \times \eta_{is} \times \eta_{gen}$ = 0.5 (1) (0.9) (0.7) (0.8) (0.95) = 0.2394

The power output is a steady value of 2736 kW or 2.7 MW from a single wind turbine in Oregon, US.

Summary

This study concludes that Wind Thermal Energy System is a viable option for storing wind power and to give a steady output to grid. The efficiency calculated for such a system is 23.94% which means that 24% of wind power can be harnessed as electricity.

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Chapter 7: Results and Conclusions

7.1 Ormara

The analysis done in this study through ARIMA and neural network BPLM models indicates both neural network and ARIMA provided similar forecasts with and performed the forecast of the time series with similar accuracy. This study also concludes that Ormara, Balochistan is a good site for wind farm installation if the parameters of the project such as height and turbine rating are set carefully. Increasing the height from the optimum value results in increase in costs without any considerable increase in power output and decreasing the height from the optimum value results in significant decrease in performance. The results show that the most suitable hub height for wind turbines in Ormara-Pakistan is 100m and capacity factor found at this height is 38.18 % with annual wind energy production of 167.22 GWh/year. This study also indicates that a 50MW wind farm in Ormara is a profitable investment with a payback period of 5 years while the project's useful life is 20 years.

After using ARIMA and ANN models for the wind prediction and techno-economic analysis for the coastal cities of Balochistan, the results obtained have been tabulated in Table 7.1.

Table 7.1- Case study results for Ormara

Parameters	**Units**	**Value**
Technical Data		
Study date	-	2015
Useful life	Years	20
Fuhrlander Wind Turbine	MW	3
No. of turbines		17
Swept area of turbine	m^2	11423
Installed Capacity	MW	50
Capacity Factor	%	38.18
Energy Generated	GWh	167
Investment		
Total Project Cost	US$ Million	126.735

EPC Cost	US$ Million	115.166
Non EPC Cost	US$ Million	11.569
Turbine Availability		95%

Benefit Cost Ratio (B.C.R)	1.22
Payback Period	5 years
Internal Rate of Return (I.R.R)	18%

7.2 Pasni

Pasni, Balochistan is an average site for wind farm installation. The optimum wind height according to present study is 100m and the appropriate wind turbine is Wind to Energy's 3MW turbine. Increasing the height from the optimum value results in increase in costs without any considerable increase in power output and decreasing the height from the optimum value results in significant decrease in performance. Electricity exported to the grid annually from a 50MW farm at Pasni is estimated as 72510MWh from which an income of 9,806,608 US $ can be generated annually. From investor's viewpoint it is safe but not very profitable to invest in this project according to the financial analysis. This is due a low resource potential at the site.

Also, it was found that Artificial neural networks were able to predict the wind speed more precisely than ARIMA models. This is because of ANN's capability of modeling non-linear relationships while ARIMA is only suitable for linear relationships.

Technical and economic analysis for Pasni yielded the following results:

Table 7.2- Case study results for **Pasni**

Parameters	**Units**	**Value**
Technical Data		
Study date	-	2015
Useful life	Years	20
Wind to Energy Wind Turbine	MW	3
No. of turbines		17
Swept area of turbine	m^2	11423
Installed Capacity	MW	50
Capacity Factor	%	16.2
Energy Generated	GWh	72.5
Investment		
Total Project Cost	US$ Million	126.735
EPC Cost	US$ Million	115.166
Non EPC Cost	US$ Million	11.569
Turbine Availability		95%

Benefit Cost Ratio (B.C.R)	0.43
Payback Period	14.5 years
Internal Rate of Return (I.R.R)	6%

7.3 Gwadar

Gwadar, Balochistan is an average site for wind farm installation. The optimum wind elevation according to present study is 100m and the appropriate wind turbine is Wind to Energy's 3MW turbine. Increasing the elevation from the optimum value results in increase in costs without any drastic increase in power output and decreasing the elevation from the optimum value results in significant decrease in performance. From investor's viewpoint it is safe but not very profitable to invest in this project according to the financial analysis. This is due to low resource potential at the site.

Again, artificial neural networks performed better than ARIMA models for wind speed prediction because of ANN's capability of capturing nonlinear trends more effectively than ARIMA.

Technical and economic analysis for Gwadar yielded the following results:

Table 7.3- Case study results for Gwadar

Parameters	**Units**	**Value**
Technical Data		
Study date	**-**	2015
Useful life	Years	20
Wind to Energy Wind Turbine	MW	3
No. of turbines		17
Swept area of turbine	m^2	11423
Installed Capacity	MW	50
Capacity Factor	**%**	13.31
Energy Generated	GWh	58.31
Investment		
Total Project Cost	US$ Million	126.735
EPC Cost	US$ Million	115.166
Non EPC Cost	US$ Million	11.569
Losses		
Array Losses		2%
Airfoil Losses		1%
Miscellaneous losses		1%
Turbine Availability		95%

7.4 Conclusions

After a detailed analysis of both ARIMA statistical models and Artificial Neural networks model we have concluded that artificial neural networks perform better where nonlinear trends and relationships are involved. Although, ARIMA is a simpler model and takes less time but for sensitive measurements such as power scheduling ANN is a better choice for power plant developers and schedulers. During the wind speed forecasting of the four cities, this comparison was obvious as ANN's forecast followed the actual values more precisely than ARIMA.

Optimization of wind farms depends on a number of factors such as accurate wind speed forecasts, optimum hub height, optimum rating and model of turbine, capacity factor and financial parameters (loans, taxes, inflation etc.).Keeping in view all of these technical and economic parameters, an analysis has been showed for the coastal areas of Balochistan which have not been previously documented in any research. By this important and conclusive research, we have determined that:

- Ormara is the most technically and financially feasible site for wind power installation and is comparable to Jamshoro and Jhimpir in Sindh as far as wind resource is concerned. Further development of Gwadar port as part of CPEC will enable cost effectiveness of wind farm in Ormara due to decrease in transportation costs of equipment to site.
- However, other cities Gwadar, Pasni and Jiwani should not be neglected. Although not very profitable like Ormara these sites offer safe investments to small scale power producers and residents who are not connected to grid electricity and are suffering from lack of electricity.

7.5 Scope and Limitations of the study

- The accuracy of forecasting results is limited by the accuracy of the data at hand, the estimation of wind profile law and innate random nature of wind that is difficult to characterize.

- For simulation work, climatic data of coastal areas of Balochistan e.g. Pasni, Jiwani, Ormara and Gwadar was taken from Pakistan Meteorological Department is taken. Climatic data for Skardu, Gilgit-Baltistan was taken from NASA's website of atmospheric database.
- Availability of data for limited sites and limited time duration.
- Until now forecasting method has been wholly accurate. Observing the trends and patterns of the time series may help in choosing the right kind of tool for forecasting.
- The number of neurons and layers in the artificial neural network architecture have been set by hit and trial method as suggested by literature review.

7.6 Recommendations

- Forecasting wind speed in various areas of Pakistan using new models: Hybrid Models, Support Vector Machine, Wavelett Packet, Fuzzy Logic
- Comparison of various models
- Identify limitations of each model
- Using hybrid systems integrating wind power with other RE sources
- Efficient storage techniques for wind power or hybrid systems

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Journals/Conference Papers

Journal Paper: Samreen Siddique, Rashid Wazir, "A review of the wind power developments in Pakistan", Renewable and Sustainable Energy Reviews, Elsevier

Conference Paper: Samreen Siddique, Rashid Wazir, Zia Ahmad Khan, Naseem Iqbal "Technical and Financial Analysis of a 50 MW Wind Farm in Gwadar, Balochistan", 2nd International Conference on Power Generation Systems and Renewable Energy Technologies IIU, Islamabad, Pakistan

Conference Paper: Samreen Siddique, Rashid Wazir, Zia Ahmad Khan, Naseem Iqbal "Techno-Economic Study of a 50 MW Wind Farm at Ormara, Balochistan", Asian Society of Management and Marketing Research, 1st National Conference, Islamabad, Pakistan.

Conference paper: Rashid Wazir, Zia Ahmed Khan, Samreen Siddique, "Techno-Economic Study for 50 MW Wind Farm in Gwadar, Balochistan", 17th IEEE Multi Topic Conference (INMIC), Karachi, Pakistan

Conference Paper: Samreen Siddique, Rashid Wazir, Zoya Siddique, "Environmental impacts of a 50MW wind farm at Ormara Pakistan", 4th International Conference on Life Sciences Research, Islamabad, Pakistan (Submitted)

Paper: Samreen Siddique, Brian Fronk, Rashid Wazir, "Modelling wind-thermal storage systems using SIMULINK", under review by faculty

Paper: Samreen Siddique, Rashid Wazir, "Study on Utilization of Wind Resource in Gilgit Baltistan, Pakistan", under review by Faculty

Paper: Samreen Siddique, Rashid Wazir, "Sources of Wind in Pakistan", under review by faculty

Conference Paper: Samreen Siddique, Rashid Wazir, Muhammad Bilal Khan Niazi "Technical and financial analysis for a 50MW wind farm in Pasni, Balochistan", Under Review by Faculty

Appendix

Paper A: Techno-economic study for 50 MW wind farm in Ormara, Balochistan

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Abstract

Purpose

Given the current power outages in Pakistan, renewable energy is a basic national need and for this purpose determining potentials of alternative energies is important. This study aims to determine the technical feasibility of wind power at Ormara along the coastal line of Baluchistan, Pakistan. This study also investigates the economic feasibility of 50 MW wind farm using Minitab, Stats Graphics, and EViews.

Methodology

To explore the power potential, four years wind speed data is forecasted using Autoregressive Integrated Moving Average (ARIMA) models and Neural Network Back propagation method. A comparison of both models has been done. For appropriate turbine selection, 317 turbines of up to 5MW of different manufacturers were examined at different heights (60m, 80m and 100m). Optimum height and model of turbine was selected to obtain maximum possible capacity factor. The results obtained from these software were validated by simulations through RETScreen Software.

Findings

The results show that the most suitable hub height for wind turbines in Ormara-Pakistan is 100m and capacity factor found at this height is 38.18 % with annual wind energy production of 167.22 GWh/year. This study also indicates that a 50MW wind farm in Ormara is a profitable investment with a payback period of 5 years while the project's useful life is 20 years.

Research Implications

Researchers, project developers and engineers can optimize wind farms by using the techniques mentioned in this paper. Using models to enhance accuracy of wind speed forecasts and wind power output is the need of the day and has direct implications on overall projects' costs.

Originality

Although similar work has been done in other parts of the world, this study is first of its kind for Balochistan where wind energy has not been exploited yet. This study is of value to researchers and investors in the wind power projects.

Limitations and Future Research

There is great room for research along the coastal line of Balochistan. . Further research on fulfilling this need for Pakistan is required to for informed financial decisions regarding installation of wind farms

Keywords: ARIMA Models, Neural Networks, Financial Decision Making, Project Management, Wind Energy Management

Article classification: Financial Decision Making, Project Management

Introduction

The crude oil price has fluctuated in the recent year from Rs.11, 298 in December 2013 to Rs. 6, 112 in December 2014 (Indexmundi n.d.). A 2012 estimate tells us that consumption of electricity was a meagre 74 billion kWh annually and electricity per consumption is one of the lowest in the world i.e. 456.64kWh per person (Indexmundi n.d.). Still, Pakistan is among the most energy deficient countries in the world. Average demand is 17000MW, decreasing in winters and increasing in summers and overall Pakistan faces a shortfall of 4500 – 5500 MW annually. Even though the total installed capacity of Pakistan is 22,797 MW, the actual generated power is less than the demand. The supply-demand gap has been growing over the past 5 years until reaching the existing levels. Such a huge gap has led to power outages of 12-16 hours per day across the country. Dependency on the fossil fuels is much higher (64.2%) because renewable energy sources have not yet penetrated enough in the energy mix with hydro accounting for 29 % and nuclear contributing 5.8% in the total energy mix. Fossil fuels cause immense harm to the environment by emitting greenhouse gases and other pollutants upon burning (Atilgan & Azapagic 2014)(Häfele et al. 1986). Pakistan spends 6% of GDP on environmental impacts which affects country's economics adversely (Hoover 2013). Most countries have therefore shifted to alternative renewable energy sources to reduce dependency on fossil fuels and minimize environmental degradation (Alnaser & Alnaser 2011). Pakistan is still emerging in the field of renewables and has not yet exploited its natural resources like solar and wind. Pakistan's 800km long coastal line along Baluchistan and 250 km along Sindh has great potential of wind power which has not been exploited even though the country bears 6MW of shortage of electricity.

Wind power has several advantages. It has low operations and maintenance cost, less environmental impact, high capacity factor and a high energy return on investment (EROI) besides being clean and renewable. The present worldwide tendency headed for investments in wind energy generation can be clarified by numerous reasons:

The wind is unrestricted and, with up-to-date machinery, it can be captured efficiently.

As soon as the wind turbine is erected, the energy it produces is clean of greenhouse gases or other pollutants.

Great rate of return.

Decent capacity factor (Salles et al. 2004)

Generating energy from a 1 MW wind turbine instead of 1 MW of conventional sources reduces yearly emissions as follows: over 1,500 tons of carbon dioxide, 6.5 tons of sulfur dioxide, 3.2 tons of nitrogen oxides, and 60 pounds of mercury in one year according to American Wind Energy Association (Pawindenergynow n.d.). If Pakistan shifts to clean renewable energy sources, the amount of money being spent on environmental impacts can be reduced. Besides, wind power farms generate between 17 and 39 times as much power as they consume, as compared to 16 times for nuclear plants and 11 times for coal plants, according to a study of Midwestern wind farms by the University of Wisconsin (Pawindenergynow n.d.). This means wind is an economically profitable source of energy if utilized wisely.

Wind speed is the most crucial factor in wind power production but because of its intermittent nature power supply is not continuous. The best practice is to predict wind speed and forecast wind power production with minimum mean absolute percentage error (MAPE). Studies have shown that accuracy of wind power forecasting is not accurate enough and different models have been applied to get best results. In this paper Auto-Regressive Integrated Moving Average (ARIMA) models Box and Jenkins methodology and Neural Networks Back Propagation method have been applied for the wind power production for the city of Ormara, Baluchistan. In this paper four -year monthly mean wind speed data (2009-2012) provided by Pakistan Meteorological Department (PMD) has been used and based on this data, monthly mean wind speed has been predicted for the next four years (2013-2016). Based on these wind speed forecasts, wind turbine is selected of appropriate rating and power output is estimated.

Models for wind speed forecast

Different models that are used worldwide for wind speed forecasting by the researchers can be categorized into physical, statistical, artificially intelligent, spatial correlation and hybrid models. Coupling two models to get a better estimate of the future wind speed series has outperformed the individual models (Shi et al. 2012). Particularly, Autoregressive moving average models have often been used along with artificially intelligent methods for better estimates (Khashei & Bijari 2011)(Zhang 2003)(Valenzuela et al. 2008).

Auto regressive moving average model is an exploratory data oriented approach which by the help of autocorrelation and partial autocorrelation function approximately models the stochastic nature of time series. ARIMA Models are composed of seasonal and non-seasonal constituents characterized by following way:

ARIMA (p,d,q)(P,D,Q)S where p,d,q is the non-seasonal portion of the model and P,D,Q is the seasonal portion of the model, S is the amount of periods per season (Cadenas & Rivera 2007). This approach is usually divided into 4 phases:

i. Identification

Usually the wind speed has seasonality so before using this model we need to remove this. This is the stage of preparation of data, in which we check either time series data is stationery or not i.e. constant mean and variance.

ii. Estimation of the parameters

Parameters are identified using ACF and PACF plot.

iii. Testing

Normality test is applied in order to fix either there is white noise or not.

iv. Prediction

Prediction is done when parameters are justified.

Artificial neural networks (ANNs) are some of the most widely used models in the last decade for wind speed forecasting and other disciplines where time series are used. Training algorithms were developed including the back-propagation (BP) algorithm, the Levenberg Marquardt (LM) algorithm to achieve the minimal value of network error (Sfetsos 2002). Appropriate treatment of the raw data is necessary for satisfactory performance in the use of neural networks (Zhang & Qi 2005).

Data collection and treatment

Wind speed data was obtained from Pakistan Meteorological Department for the years 2009-2012. PMD has meteorological observatories installed all over the country: 28 in Punjab, 19 in KPK, 9 in northern areas and 27 in Sindh & Balochistan provinces. The observatory in Ormara-Balochistan is located at 25^{o} 12' latitude and 64^{o}40' longitude at an elevation of 2m. The received raw data was treated to remove seasonality and stationarity by differencing method. The time series of the wind speed series was then plotted using Minitab software as shown in Figure 1.

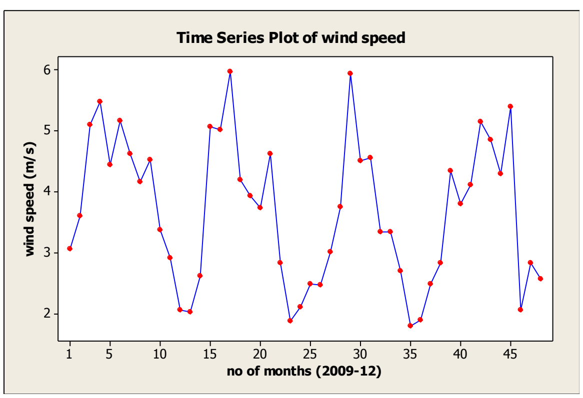

Figure 12-Wind speed time series for Ormara-Balochistan

Identification of statistical model

This randomness is checked by computing autocorrelations for values in the data at varying time lags. Autocorrelations near zero indicate randomness in the data. If non-random, then one or more of the autocorrelations will be significantly non-zero. A significant value at lag 1 is seen. Rest of the values are within the 95% confidence band as shown in Figure 2.

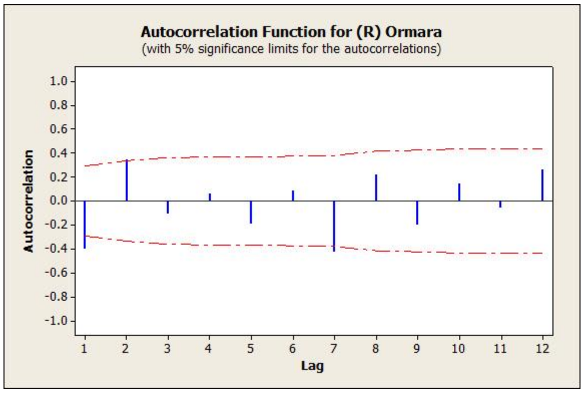

Figure 13-Autocorrelation plot

Partial autocorrelation plot helps identify the model in Box & Jenkins methodology. Partial correlation graph shows significance at lags1 and 7. Rest of the values are in the 95% confidence band as shown in Figure 3.

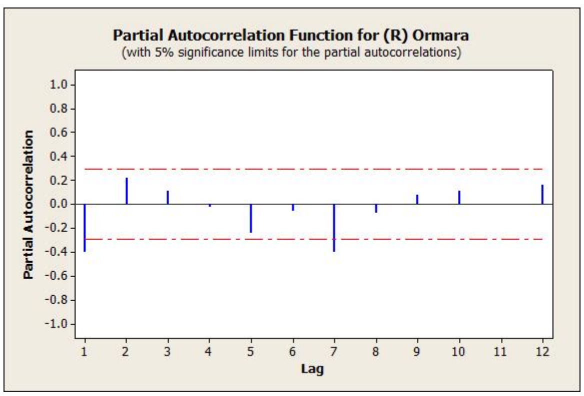

Figure 14-Partial Autocorrelation plot

Testing

Normality test is run to check the goodness of fit of a model to the data. A *p* value exceeding 0.05 means that there no white noise error terms and the data has been well modeled. Normality test has been satisfied in this case as shown in Figure 4.

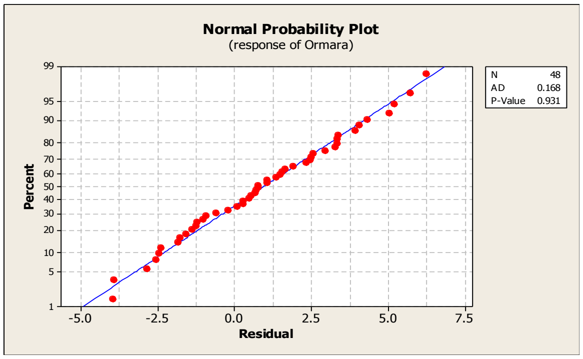

Figure 15-Normality test

A first-order autoregressive and moving average model-ARIMA (1, 0, 1) was used on the observed series. Its mean forecasted wind speed depends on previous time period value, random value plus moving average of last two terms. The forecasting equation fitted by Statgraphics is:

$\hat{Y}_t = \mu + \phi_1 Y_{t-1} - \theta_1 e_{t-1}$

Where $\hat{Y}_t$ represents values in the forecasted series and Y_{t-1} represents the past value in the original series, the last term of the equation $\theta_1 e_{t-1}$ represents white noise and μ is the moving average term. The forecasted series was plotted along with the original series was plotted as shown in Figure 5.

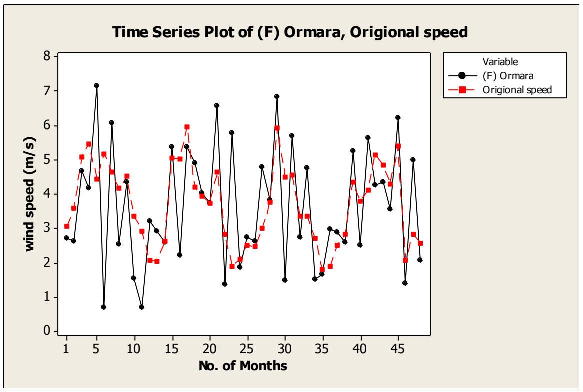

Figure 16-Original wind speed series vs Forecasted wind speed series using ARIMA Box & Jenkins methodology

Artificial Neural Networks

Neural networks are a nonlinear modeling approach which provide an approximation to any function with a fair accuracy. It has been closely associated with the statistical techniques with regards to its applications for model fitting. The prediction model has a generalized form:

$$X_t = f\left(X_{t-1}, X_{t-2}, \ldots, X_{t-p} \right) + e_t$$

With proper designing of the network and parameters, satisfactory performance of the forecasts can be achieved with the help of neural networks. Neural network architectures are properly trained to forecast a particular time series.

Back-propagation Levenberg-Marquardt (BPLM) algorithm for neural networks was used in this study to predict wind speed of the year 2013-2016 for Ormara, Balochistan. The wind speed series obtained from the meteorological observatory was projected to a height of 100m using the wind profile power law. As the previous test in figure 2 and 3 showed that one past value was significant for predicting the series, the lag value was set as 1. The number of hidden neurons were set as 14. Wind speed forecasts for the year 2013-2016 were obtained as shown in figure 6.

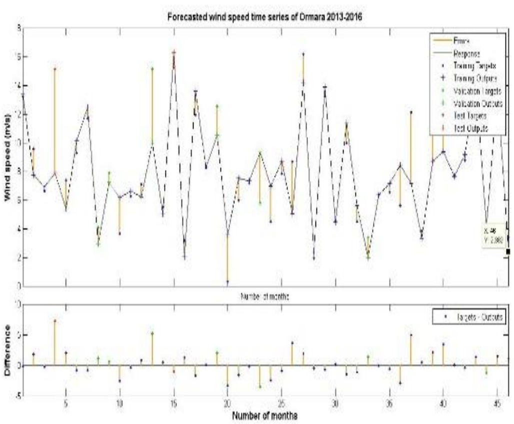

Figure 17- Wind speed forecasted series using neural network backpropagation method

The mean square errors obtained by the modelling are as shown in Figure 7.

Results

	Target Values	MSE	R
Training:	39	3.13853e-0	8.89990e-1
Validation:	7	6.88522e-0	8.28299e-1
Testing:	2	26.89209e-0	1.00000e-0

Figure 7-Mean square error and R values for neural network backpropagation method

Comparison

The results obtained from both methodologies i.e. ARIMA and Backpropagation Levenberg-Marquardt algorithm for neural networks were compared. Similarity and consistency in the trend was observed in the forecasted series as shown in Figure 8.

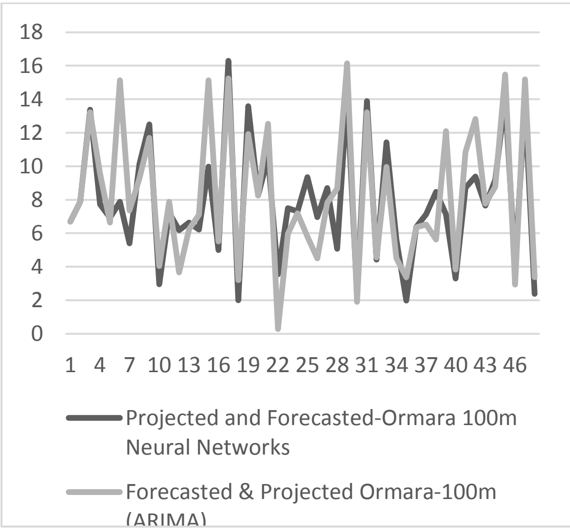

Figure 8-Comparing the forecasted series obtained using ARIMA models and BPLM-NN method

The average speed from the ARIMA forecast at 100m was 7.95 m/s whereas for 60m and 80m the average value of the forecast was found out to be 7.17m/s and 7.60 m/s respectively. The average speed from the neural networks BPLM method was found out to be 7.863 m/s. Hence a difference of 1% was observed between the forecasted ARIMA values and NN values.

Turbine selection and wind power generation

For wind power generation, Fuhrlander Wind Turbine with capacity of 3000 kW was chosen. To find out the actual power generation, it is necessary to consider the power curve of selected turbine as shown in Figure 9.

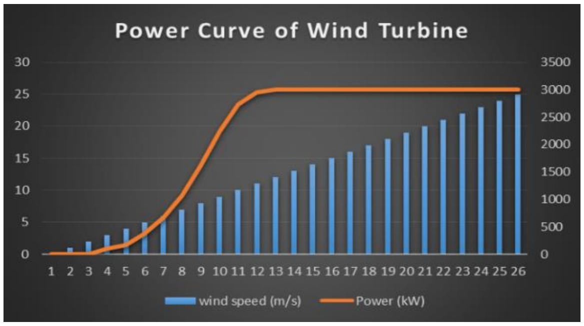

Figure 18-Power curve of the Fuhrlander 3MW wind turbine

It indicates how much the wind power can be extracted from wind turbine. It is assessed by an anemometer located at locked to wind turbine in areas with low turbulence intensity.

The selected wind turbine has a cut in speed of 3 m/s and cut out speed of 26 m/s. A wind turbine capture its energy by part of kinetic energy of the wind that goes through swept area of the rotor and convert the force into torque acting on the rotor blades. In the range between the cut in speed and rated speed electric power is generated is a function of cube of wind speed. $P = 0.5\rho A_r C_p \eta V^3$

Where,

ρ = air density 1.184 kg/m^3 at 25^o C

A_r = rotor area

C_p = aerodynamic power coefficient of rotor

η = efficiency of generator i.e. 97%

As wind profile gets smoother and smoother at high altitudes. At 100 m height we get best wind profile so we project forecasted wind speed from 9m into 100 m taking surface roughness 0.20.

α Is called power law exponent. It is dimension less factor. It varies with altitude, time of the daytime, periods of the year, nature of topography. It varies from 0.10 (smooth terrain) to 0.40 (very rough terrain). For our study the value of alpha was set at 0.2.

The wind speed obtained from the forecast, as mentioned in Table 1, was used to estimate wind power generation and financial analysis.

Table 4- Characteristics of the forecasted wind speed

Minimum (m/s)	1.50

Maximum (m/s)	15.659
Mean (m/s)	7.951
Standard Deviation	3.750
Capacity Factor (%)	38.18

Case Study

To utilize the wind speed of Ormara, Balochistan a hypothetical case study was done. The investment cost is 126.735 million US$. It includes EPC cost, Non-EPC cost, Interest during Constructions (IDC). The capacity factor was calculated as 38.12%.

Table 5- Parameters chosen for case study

Parameters	Units	Value
Technical Data		
Study date	-	2015
Useful life	Years	20
Fuhrlander Wind Turbine	MW	3
No. of turbines		17
Swept area of turbine	m^2	11423
Installed Capacity	MW	50
Capacity Factor	%	38.18
Energy Generated	GWh	167
Investment		
Total	US$	126.735

Project Cost	Million	
EPC Cost	US$ Million	115.166
Non EPC Cost	US$ Million	11.569
Losses		
Array Losses		5%
Airfoil Losses		2%
Miscellaneous losses		2%
Turbine Availability		95%

Keeping same all the parameters, RETScreen financial analysis was performed and a capacity factor of 41% was achieved. Increase in 3% of capacity factor from numerical calculations may be due to not considering exact probability density function of wind speed taken according to Weibull parameters. Without considering the wind speed uncertainty, financial analysis is performed and results are given in Table 3.

Table 6-Financial Analysis

Net Present Value (NPV):	29801236.41 US$
Benefit Cost Ratio (B.C.R)	1.22
Payback Period	5 years
Internal Rate of Return (I.R.R)	18%
Sensitivity Analysis	
10% prices increase (I.R.R)	15%

10% prices decrease (I.R.R)	20%

Conclusion

The analysis done in this study through ARIMA and neural network BPLM models indicates both neural network and ARIMA provided similar forecasts with and performed the forecast of the time series with similar accuracy. This study also concludes that Ormara, Balochistan is a good site for wind farm installation if the parameters of the project such as height and turbine rating are set carefully. Increasing the height from the optimum value results in increase in costs without any considerable increase in power output and decreasing the height from the optimum value results in significant decrease in performance. The optimum wind height according to present study is 100m and the optimum wind turbine is Fuhrlander's 3MW turbine. The forecasted wind speed has mean absolute percentage error of 12.984%. From investor's viewpoint it is profitable to invest in this project according to the financial analysis.

Acknowledgements

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Paper B: Technical and financial analysis of 50MW wind farm at Gwadar, Balochistan

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Abstract— Statistical and computational models have been used worldwide by the researchers to forecast time series. This paper implements two techniques; Autoregressive Integrated Moving Average models and Neural Networks backpropagation algorithm to predict wind speed time series for Gwadar, a coastal city of Balochistan. Based on the wind speed forecast, power output has been estimated for a 50MW wind farm, choosing the appropriate turbine and optimum hub elevation for the installation of wind turbine. Furthermore, a financial study is presented of such a wind farm at Gwadar. For turbine selection, 317 turbines of various ratings and manufacturers were surveyed through software at different elevations - 60m, 80m, 100m and 120m. The results show that Neural Networks capture the trend in the wind speed time series more accurately than its statistical counterpart. Also, the optimum hub elevation for installing wind turbine at Gwadar is found to be 100m. Annual energy production under these circumstances is found to be 58.31 GWh/year.

Keywords— wind farm optimization; Neural networks; ARIMA; Wind power forecasting

Introduction

Pakistan's electricity demand per person is one of the lowest globally, a meagre 456.64 kWh [1]. Still, Pakistan has managed to make it to the list of world's most energy deficient countries. The existing energy crisis in Pakistan has received a lot of attention worldwide since a 2013 report declared Pakistan to be among the ten countries facing the worst energy crisis in the world. There are about 1.3 billion people in the world who are living without electricity and sixty six percent of them are in ten countries and Pakistan is one of them [2]. The crude oil price halved in the past year from.11, 298 rupees per barrel in 2013 to 6, 112 rupees in 2014 [3]. The electricity demand in Pakistan peaks in summer and decreases in winter with an overall shortage of 4500 – 5500 MW of supply annually [4] [5]. The past decade has particularly experienced most power outages with load shedding hours reaching up to 16 across the country [6]. There are number of reasons contributing to the power crisis, the major being the dependency on fossil fuels and lack of renewable energy systems. However, solar and wind technologies are emerging. The glaring use of fossil fuels has had many negative impacts on the environment and economics. It is a known fact that fossil fuels emit greenhouse gases and other pollutants when burnt causing harm to the environment. [7], [8]. Pakistan fights environmental degradation by spending 6 percent of the gross domestic product (GDP) to counter the damage [9]. Countries all around the world have learnt from the past and are shifting to clean energy sources minimizing environmental degradation and boosting their economies [10]. Wind power is one of the popular options and is considered an emerging renewable technology free of greenhouse gas emissions in the operation phase. One report states that annual emissions offset by generating energy using a 1 MW wind turbine replacing fossil fuels are 1,500 tons of carbon dioxide, 6.5 tons of sulfur dioxide, 3.2 tons of nitrogen oxides and 60 pounds of mercury in a year [11].

Pakistan has a 1050 km long coastal line with great wind power potential awaiting utilization [12]. Solar and biomass have been receiving more attention in the country than wind [13]. Wind mapping and various reports indicate a great wind power potential in Pakistan which have not been utilized and efforts are required for development [14][15]. Boosting energy production by diversifying the energy resources will not only solve energy shortage problems of the country but also affect poverty and unemployment positively [16]. Therefore, Pakistan aims to have at least 5 percent contribution from wind and solar power by 2030 [17]. To fulfil its vision, it is imperative that good surveys are carried out to determine possibilities of future projects.

The speed of the wind is the most important factor in wind power but because of its intermittent nature power supply is not constant. The standard practice is to predict wind speed and then predict wind power production with minimum error. In this study, the Box and Jenkins methodology of Auto-Regressive Integrated Moving

Average (ARIMA) models and Neural Networks' Back Propagation method have been used to predict wind speed for the city of Gwadar. Four year monthly mean wind speeds were provided by Pakistan Meteorological Department (PMD) for the year 2009- 2012. Based on this data, monthly wind speed is forecasted for the years 2013-2016. Basing on these forecasts, selection of wind turbine has been done and power output has been estimated.

MODELS USED FOR WIND SPEED ESTIMATES

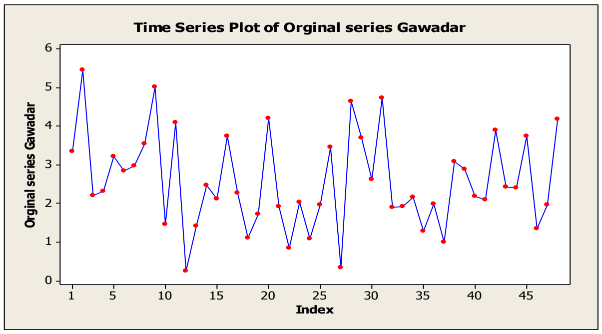
Many models that are used globally for wind speed prediction by the scholars can be classified into statistical, physical, artificially intelligent and hybrid models. Hybridization of two models to get a better forecast of the future time series has surpassed the individual models in performance [18]. Particularly, ARIMA models have been used coupled with artificially intelligent methods for better forecasts [19][20][21].

Autoregressive moving average model is an investigative data oriented method which by the aid of partial autocorrelation and autocorrelation function approximately estimates the stochastic time series. These models are made of seasonal and non-seasonal components characterized by following way: ARIMA (p,d,q)(P,D,Q)S in which p,d,q is the non-seasonal part and P,D,Q is the seasonal part of the model, and S is the amount of periods in one season [22]. The wind speed time series has seasonality so before using this model seasonality is removed. Raw data is treated and time series is assessed for stationarity. Then, parameters are identified using autocorrelation and partial auto correlation function graphs. Normality test is run to fix white noise. Finally, prediction is done

Artificial neural networks are widely used models for time series analysis and predicting particularly wind speed time series. The back-propagation (BP) algorithm, the Levenberg Marquardt (LM) algorithm were developed as training models to achieve a minimal value of error [23]. Treatment of raw data is required for good performance of neural networks [24].

DATA COLLECTION AND TREATMENT

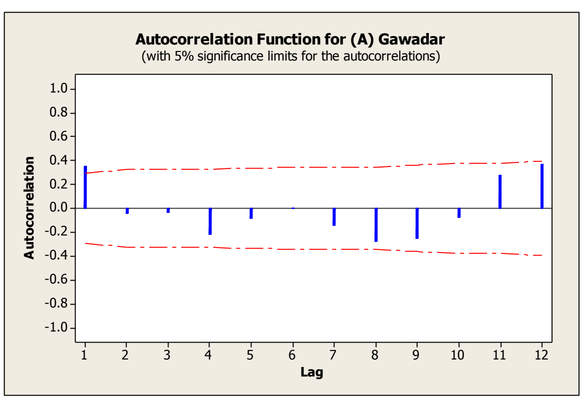
Wind speed monthly mean data was collected from the Pakistan Meteorological Department of 2009-2012. The meteorological observatory in Gwadar-Balochistan is located at 25^o 08' latitude and 62^o 20' longitude at an elevation of 29.86 meters. The raw data was treated to eliminate seasonality and stationarity using the method of differencing. The wind speed time series was then graphed using Minitab software as shown in Fig. 1.



Wind speed time series for Gwadar-Balochistan

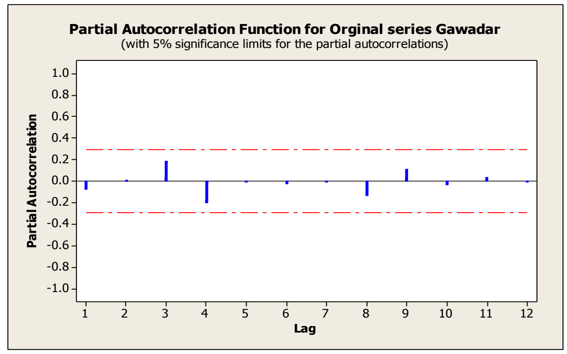
IDENTIFICATION OF STATISTICAL MODEL

The randomness in data was assessed by autocorrelations at varying time lags. Autocorrelations near zero mean randomness in the data. If non-random, one or more of the autocorrelations are significantly non-zero. A significant value at lag 1 was found. Rest of the values were within 95% confidence interval as shown in Fig. 2.



Autocorrelation graph

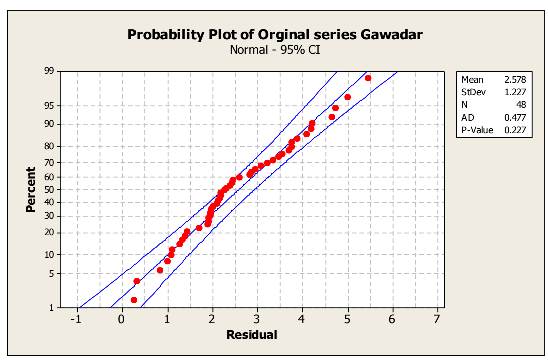
Partial autocorrelation graph is used to identify the model in Box and Jenkins methodology. Partial correlation graph here shows that all values lie in the 95% confidence interval as shown in Fig. 3.



Partial Autocorrelation graph

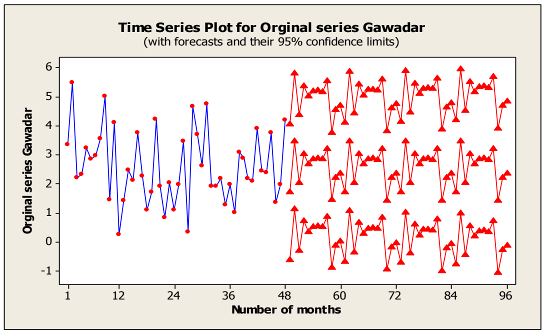
TESTING

Normality test is run to assess the goodness of fit of a model to the data. A *p* value exceeding 0.05 means that there no white noise error terms and the data has been well modeled. Normality test has been satisfied in this case as shown in Fig. 4.



Normality test

A first-order autoregressive and moving average model-ARIMA (1, 0, 1) was used. This indicates that the predicted wind speed depends on the past value, random value and moving average of last two terms. The predicted series was graphed along with the real-time series as shown in Fig. 5.



Real-time wind speed series vs Predicted wind speed series using ARIMA Box & Jenkins methodology with their 95% confidence limits

ARTIFICIAL NEURAL NETWORKS

Neural networks are a nonlinear modeling method which provide an approximation to any function with a fair accuracy. It has been closely associated with the statistical techniques with regards to its applications for model fitting. The prediction model has a generalized form:

$$X_t = f\left(X_{t-1}, X_{t-2}, \dots, X_{t-p}\right) + e_t$$

Wind speed predicts were achieved using nnstart tool in MATLAB by Backpropagation neural networks method as shown in Figure 6. With proper designing of the network and parameters, satisfactory performance of the forecasts can be achieved with the help of neural networks. Neural network architectures are properly trained to predict a particular time series.

Back-propagation Levenberg-Marquardt (BPLM) algorithm for neural networks was used in this study to predict wind speed of the year 2013-2016 for Gwadar, Balochistan. The wind speed series achieved from the meteorological observatory was projected to an elevation of 100m using the wind profile power law. As the past tests in figure 2 and 3 showed that first past value was significant for predicting the series, the lag value was set as 1. The number of hidden neurons were set as 13. Wind speed predicts for the year 2013-2016 were achieved as shown in Fig. 6.

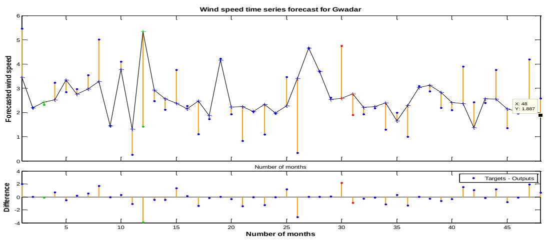
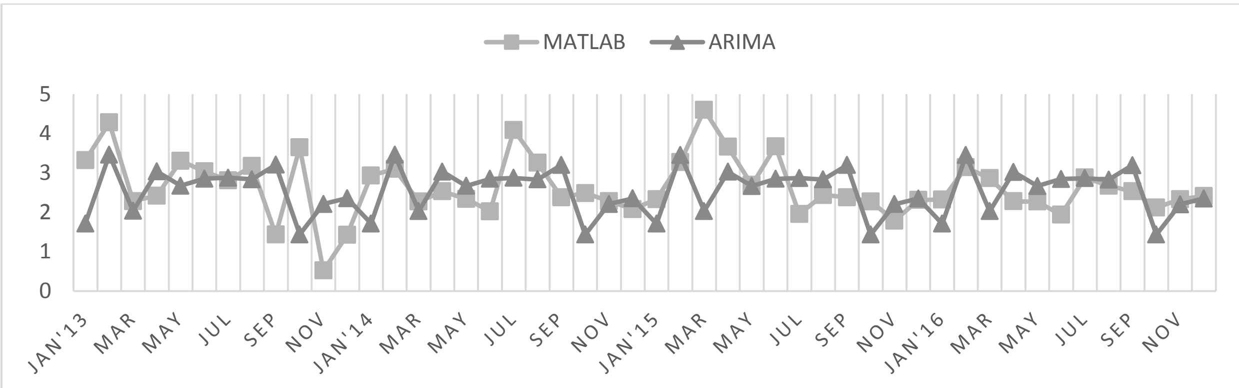


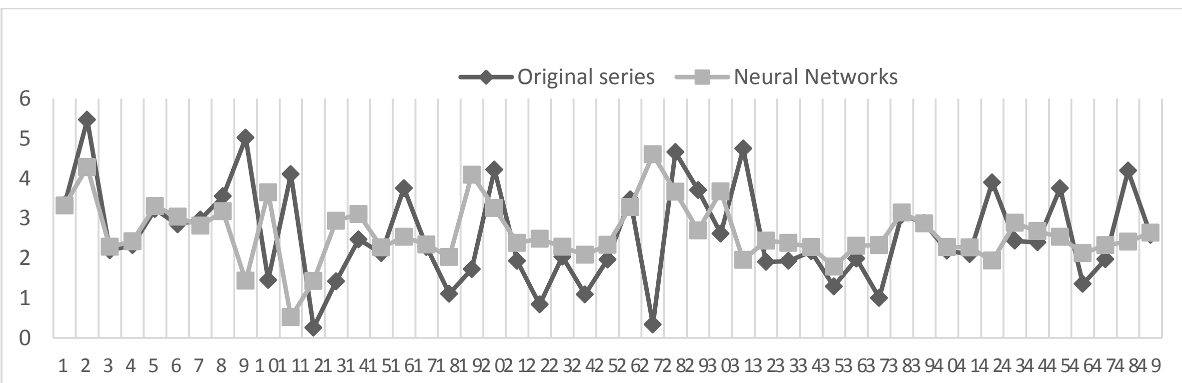
Fig. 6. Wind speed forecasted series using neural network backpropagation method

COMPARISON

The results achieved from both methodologies i.e. ARIMA and Backpropagation Levenberg-Marquardt algorithm for neural networks were compared. Forecasts achieved from both models were not entirely similar as shown in Fig. 7. It is seen that neural networks are more successful in capturing the trends and variations in the real-time time series as shown in Fig. 8. The better performance of neural networks is because of their flexible nonlinear modeling ability. With ANNs, there is no need to indicate a particular model form. Rather, the model is adaptively formed based on the features presented from the data. Past study for Ormara, Balochistan indicated more coherence among the two models [25].



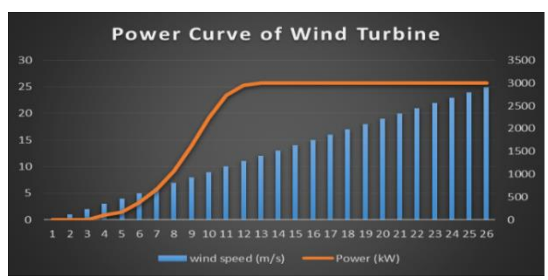
Neural networks' forecast vs real-time time series



Performance of neural networks as a forecating tool

TURBINE SELECTION AND WIND POWER GENERATION

For wind power generation, Wind to Energy's turbine with capacity of 3000 kW was chosen. To find out the actual power generation, it is necessary to consider the power curve of selected turbine as shown in Fig. 9.



Power curve of Wind to Energy turbine

It indicates how much the wind power can be extracted from wind turbine. It is assessed by an anemometer located at locked to wind turbine in areas with low turbulence intensity.

The selected wind turbine has a cut in speed of 3 m/s and cut out speed of 26 m/s. A wind turbine capture its energy by part of kinetic energy of the wind that goes through swept area of the rotor and convert the force into torque acting on the rotor blades. In the range between the cut in speed and rated speed electric power is generated is a function of cube of wind speed.

$$P = 0.5\rho A_r C_p \eta V^3$$

Where, ρ = air density 1.184 kg/m^3 at 25^o C, A_r = rotor area, C_p = aerodynamic power coefficient of rotor, η = efficiency of generator i.e. 97%

Financial Analysis

To utilize the wind speed of Gwadar, Balochistan a hypothetical case study was done. The investment cost is 126.735 million US$. It includes EPC cost, Non-EPC cost, Interest during Constructions (IDC).

EPC costs breakdown is as follows:

Agreement with turbine developer including nacelle, hub, blades, SCADA system (59.313 million US $)), transportation till Karachi port and from Karachi port to site (13.847 million US $), towers (11.17 million US $), civil works (12.876 million US $), electrical works (12.340 million US $), project management and supervision (4.732 million US $), other EPC costs for surveys, maps (1.00 million US $).

Non-EPC cost breakdown is as follows:

Cost of consultants (1.5 million US $), administration during construction (0.832 million US $)), licenses and other legal costs (0.038 million US $)), insurance cost during construction (1.35% of EPC cost = 1.44 million US $)), other projects costs (1.872 million US $)), financial charges (3.129 million US $)), and interest during construction (2.712 million US $)).

It is proposed that 80% of the total project cost will be financed through loans from commercial banks. 100% debt will be in foreign currency and be indexed with the current LIBOR rate at 2.88%. Loan period will be 10 years plus 1 year grace period. It has been supposed that loan is to be repaid in quarterly payments and premium/spread over LIBOR is 3.15%. Since, NEPRA has announced an upfront tariff of 13.52 cents per kWh for wind power projects[17] the electricity export rate was set as 135.244 $/MWh. A summary of the project is presented in Table 1.

Parameters chosen for case study

Parameters	Units	Value
Technical Data		
Study date	-	2015

Useful life	Years	20
Wind to Energy Wind Turbine	MW	3
No. of turbines		17
Swept area of turbine	m^2	11423
Installed Capacity	MW	50
Capacity Factor	%	13.31
Energy Generated	GWh	58.31
Investment		
Total Project Cost	US$ Million	126.735
EPC Cost	US$ Million	115.166
Non EPC Cost	US$ Million	11.569
Losses		
Array Losses		2%
Airfoil Losses		1%
Miscellaneous losses		1%
Turbine Availability		95%

According to the Pakistan's renewable energy policy, the wind speed risk is borne by the purchase. So without considering the wind speed uncertainty, the financial analysis has been performed and results are given in Table 2.

Financial Analysis

Parameters	Value
Benefit Cost Ratio (B.C.R)	1.04
Payback Period	9 years
Internal Rate of Return (I.R.R)	13%

Conclusion

Gwadar, Balochistan is an average site for wind farm installation. The optimum wind elevation according to present study is 100m and the appropriate wind turbine is Wind to Energy's 3MW turbine. Increasing the elevation from the optimum value results in increase in costs without any drastic increase in power output and decreasing the elevation from the optimum value results in significant decrease in performance. From investor's viewpoint it is safe but not very profitable to invest in this project according to the financial analysis. This is due to low resource potential at the site.

Acknowledgements

The authors wish to acknowledge Dr. Muhammad Bilal Khan, Principal CAS-EN, Ms. Humaira Gul and Dr. Zamir Hussain Assistant Professor Department of Research Centre for Modelling and Simulations RCMS-(NUST) for their help and cooperation.

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Paper C: Technical and financial analysis for a 50MW wind farm at Pasni, Balochistan

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Abstract-Given the current power outages in Pakistan, renewable energy is a basic national need and for this purpose determining potentials of alternative energies is important. This study aims to determine the technical feasibility of wind power at Pasni along the coastal line of Balochistan, Pakistan. This study also focuses on financial aspects of a 50 MW wind farm using Minitab, Stats Graphics, and EViews. To explore the power potential, four years' wind speed data has been forecasted using Autoregressive Integrated Moving Average (ARIMA) models and Neural Network Back propagation method. A comparison of both models has been done. For appropriate turbine selection, 317 turbines of varied ratings and of different manufacturers were examined at different heights (60m, 80m and 100m). Optimum height and model of turbine was selected to obtain maximum possible capacity factor. The results obtained from this study were validated by simulations through RETScreen software. The results show that the most suitable hub height for wind turbines in Pasni, Pakistan is 100m and capacity factor found at this height is 16.2% with annual wind energy production of 72.5 GWh/year.
Keywords—Neural networks; ARIMA; Wind power forecasting; wind farm optimisation

I. INTRODUCTION

About 1.3 billion people in the world are living without electricity; two-thirds of them being in ten countries and Pakistan is among them, facing the worst energy crisis in the world according to the Statistical Yearbook for Asia and the Pacific-2013 [1]. The crude oil price has declined in the recent year from Rs.11, 298 in December 2013 to Rs. 6, 112 in December 2014 [2]. A 2012 estimate tells us that consumption of electricity was a meagre 74 billion kWh annually and electricity consumption is one of the lowest in the world i.e. 456.64 kWh per capita [3]. Still, Pakistan is among the most energy deficient countries in the world. Average demand is 17000MW decreasing in winters and increasing in summers and overall Pakistan faces a shortfall of 4500 – 5500 MW annually [4]. Even though the total installed capacity of Pakistan is 22,797 MW the actual generated power is less than the demand [5]. The supply-demand gap has continuously grown over the past 5 years until reaching the existing levels. Such an enormous gap has led to load-shedding of 12-16 hours across the country [6]. This is attributed to the dependency on the fossil fuels which is much higher (64.2%) and that, renewable energy sources have not yet penetrated enough in the energy mix with hydro accounting for 29 % and nuclear contributing only 5.8% in the total energy mix. In addition, fossil fuels cause immense harm to the environment by emitting greenhouse gases and other pollutants upon burning [7][8]. To fight environmental degradation, the country spends 6% of GDP on environmental impacts which has affected its economics adversely [9]. In view of this, most countries have therefore shifted to alternative renewable energy sources to reduce dependency on fossil fuels and minimize environmental degradation [10]. One of the emerging renewable technologies is wind power which has been found to be free of emissions except for its construction phase. American Wind Energy Association states that yearly emissions eliminated by generating energy from a 1 MW wind turbine instead of 1 MW of conventional sources are over 1,500 tons of carbon dioxide, 6.5 tons of sulfur dioxide, 3.2 tons of nitrogen oxides, and 60 pounds of mercury in annually. Depending upon resource potential, wind power farms generate between 17 and 39 times as much power as they consume, as compared to 16 times for nuclear plants and 11 times for coal plants, according to a study of Midwestern wind farms by the University of Wisconsin [11].

Pakistan is still emerging in the field of renewables and has not yet exploited its natural resources like solar and wind. Pakistan's 800km long coastal line along Baluchistan and 250 km along Sindh has great potential of wind power which has not been utilized even though the country faces 6MW of shortage of electricity [12]. Among the renewables solar and biofuels have received more attention as compared to other renewables [13]. The drivers for wind technology penetration are declining wind costs, fuel price uncertainty, federal and state policies, economic development, environment, public support, green power, energy security and carbon risk [14]. Studies have shown that the potential for wind power exists but has not been utilized yet and significant efforts are required [15][16]. It has already been suggested by various studies that boosting energy production by diversifying the energy resources will have many direct and indirect positive impacts on poverty alleviation and unemployment [17]. Also, it has been predicted that within ten years, solar and wind power will be the cheapest forms of energy production for Asia's largest energy markets [18]. Pakistan is aiming to achieve at least 5% wind power in its energy mix by 2030 [20]. To fulfil its vision, it is imperative that good surveys are carried out to determine possibilities of future projects.

Wind power has several advantages. It has low operations and maintenance cost, less environmental impact, high capacity factor and a high energy return on investment (EROI) besides being clean and renewable. The present worldwide tendency headed for investments in wind energy generation can be clarified by numerous reasons:

- The wind is unrestricted and, with up-to-date machinery, it can be captured efficiently.
- As soon as the wind turbine is erected, the energy it produces is clean of greenhouse gases or other pollutants.
- Great rate of return.
- Decent capacity factor [19]

Wind speed is the most crucial factor in wind power production but because of its intermittent nature power supply is not continuous. The best practice is to predict wind speed and forecast wind power production with minimum mean absolute percentage error (MAPE). In this paper Auto-Regressive Integrated Moving Average (ARIMA) models Box and Jenkins methodology and Neural Networks Back Propagation method have been used for wind speed prediction for the city of Pasni, Baluchistan. In this paper four -year monthly mean wind speed data (2009-2012) provided by Pakistan Meteorological Department (PMD) has been used and based on this data, monthly mean wind speed has been predicted for the next four years (2013-2016). Relying on these wind speed forecasts, wind turbine has been selected of appropriate rating and power output is estimated.

II. MODELS FOR WIND SPEED FORECAST

Different models that are used worldwide for wind speed forecasting by the researchers can be categorized into physical, statistical, artificially intelligent, spatial correlation and hybrid models. Coupling two models to get a better estimate of the future wind speed series has outperformed the individual models [21]. Particularly, Autoregressive moving average models have often been used along with artificially intelligent methods for better estimates [22][23][24].

Auto regressive moving average model is an exploratory data oriented approach which by the help of autocorrelation and partial autocorrelation function approximately models the stochastic nature of time series. ARIMA Models are composed of seasonal and non-seasonal constituents characterized by following way: ARIMA (p,d,q)(P,D,Q)S where p,d,q is the non-seasonal portion of the model and P,D,Q is the seasonal portion of the model, S is the amount of periods per season [25]. This approach is usually divided into 4 phases:

- Identification- Usually the wind speed has seasonality so before using this model we need to remove this. This is the stage of preparation of data, in which we check either time series data is stationery or not i.e. constant mean and variance.
- Estimation of the parameters- Parameters are identified using ACF and PACF plot.
- Testing-Normality test is applied in order to fix either there is white noise or not.

- Prediction- Prediction is done when parameters are justified.

Artificial neural networks (ANNs) are some of the most widely used models in the last decade for wind speed forecasting and other disciplines where time series are used. Training algorithms were developed including the back-propagation (BP) algorithm, the Levenberg Marquardt (LM) algorithm to achieve the minimal value of network error [26]. Appropriate treatment of the raw data is necessary for satisfactory performance in the use of neural networks [27].

III. DATA COLLECTION AND TREATMENT

Wind speed data were obtained from Pakistan Meteorological Department for the years 2009-2012. PMD has meteorological observatories installed all over the country: 28 in Punjab, 19 in KPK, 9 in northern areas and 27 in Sindh & Balochistan provinces. The observatory in Pasni- Balochistan is located at at 25o16' latitude and 63o 29' longitude at 9m. The received raw data were treated to remove seasonality and stationarity by differencing method. The time series of the wind speed series was then plotted using Minitab software as shown in Fig. 1.

Fig. 1. Wind speed time series for Pasni-Balochistan 45 40 35 30 25 20 15 10 5 1 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 Index (A) Pasni Time Series Plot of (A) Pasni

IV. IDENTIFICATION OF STATISTICAL MODEL

This randomness is checked by computing autocorrelations for values in the data at varying time lags. Autocorrelations near zero indicate randomness in the data. If non-random, then one or more of the autocorrelations will be significantly non-zero. A significant value at lag 1 is seen. Rest of the values are within the 95% confidence band as shown in Fig. 2. Autocorrelation and partial autocorrelation as in Fig.3 plots help in identifying the model of ARIMA and also indicate which past values are significant in the forecasts.

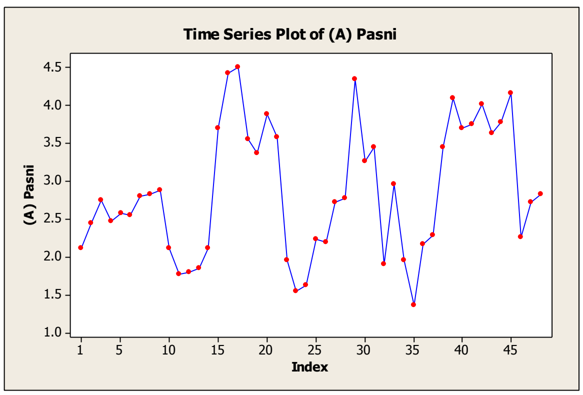

Fig. 19. Wind speed time series for Pasni-Balochistan

IDENTIFICATION OF STATISTICAL MODEL

This randomness is checked by computing autocorrelations for values in the data at varying time lags. Autocorrelations near zero indicate randomness in the data. If non-random, then one or more of the autocorrelations will be significantly non-zero. A significant value at lag 1 is seen. Rest of the values are within the 95% confidence band as shown in Fig. 2. Autocorrelation and partial autocorrelation as in Fig.3 plots help in identifying the model of ARIMA and also indicate which past values are significant in the forecasts.

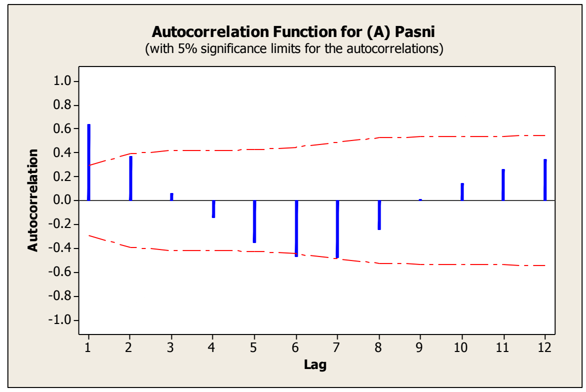

Fig. 20. Autocorrelation plot

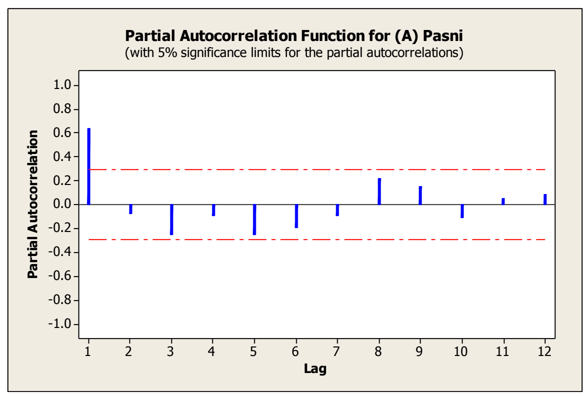

Fig. 21. Partial autocorrelation plot for wind speed time series at Pasni. All values are within limits except at lag 1

TESTING

Normality test is run to check the goodness of fit of a model to the data. A p value exceeding 0.05 means that there no white noise error terms and the data has been well modeled. Normality test has been satisfied in this case as shown in Fig. 4.

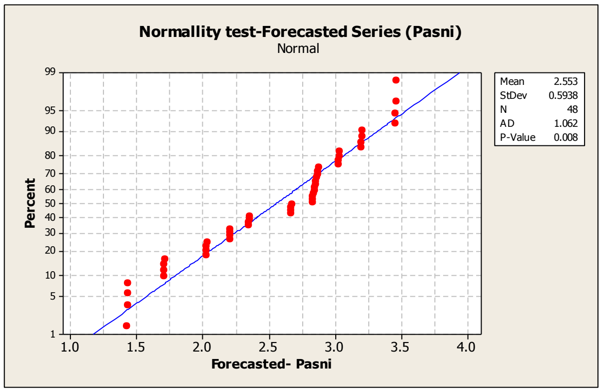

Fig. 22. Normality test

A first-order autoregressive and moving average model-ARIMA (1, 0, 1) was used on the observed series. This indicates that the forecasted wind speed depends on the previous value, random value and moving average of last two terms. The forecasted series was plotted along with the original series was plotted as shown in Fig. 5.

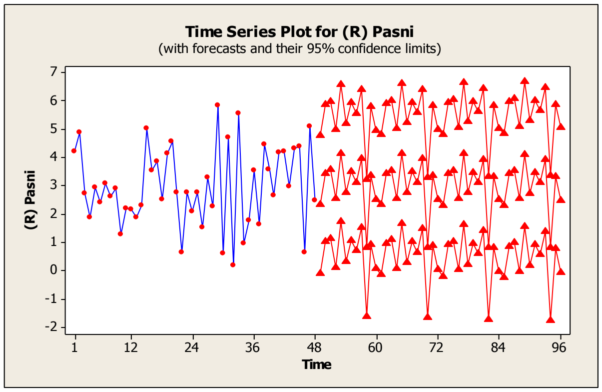

Fig. 23. Original wind speed series vs Forecasted wind speed series using ARIMA Box & Jenkins methodology with their 95% confidence limits

ARTIFICIAL NEURAL NETWORKS

Back-propagation Levenberg-Marquardt (BPLM) algorithm for neural networks was used in this study to predict wind speed of the year 2013-2016 for Pasni, Balochistan. The wind speed series obtained from the meteorological observatory was projected to a height of 100m using the wind profile power law. As the previous test in figure 2 and 3 showed that one past value was significant for predicting the series, the lag value was set as 1. The number of hidden neurons were set as 13. Wind speed forecasts for the year 2013-2016 were obtained as shown in Fig. 6.

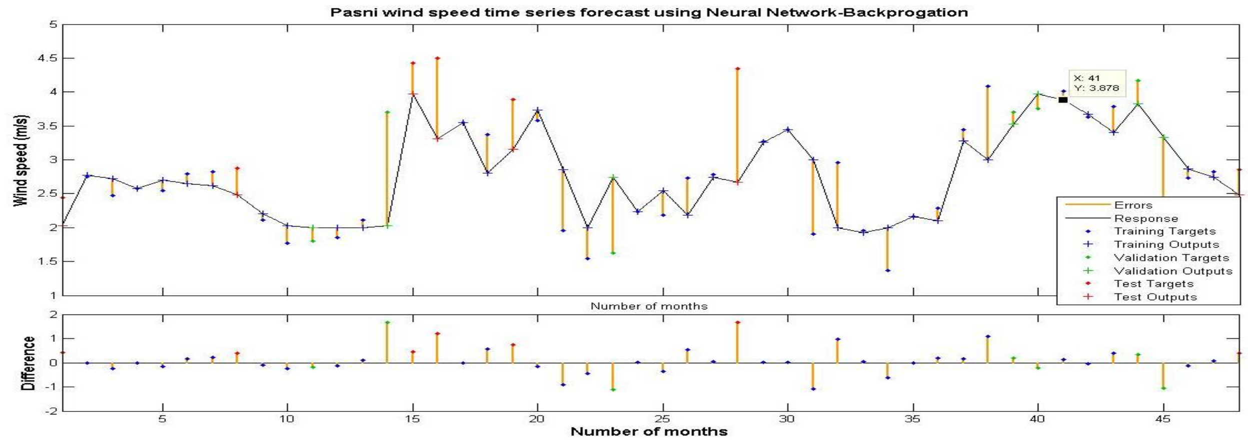

Fig. 24. Wind speed forecasted series using neural network backpropagation method

COMPARISON

The results obtained from both methodologies i.e. ARIMA and Backpropagation Levenberg-Marquardt algorithm for neural networks were compared. Forecasts obtained from both models were not entirely similar as shown in Fig. 7. It is observed that neural networks have been more successful in capturing the trends and variations in the original time series as shown in Fig.8.

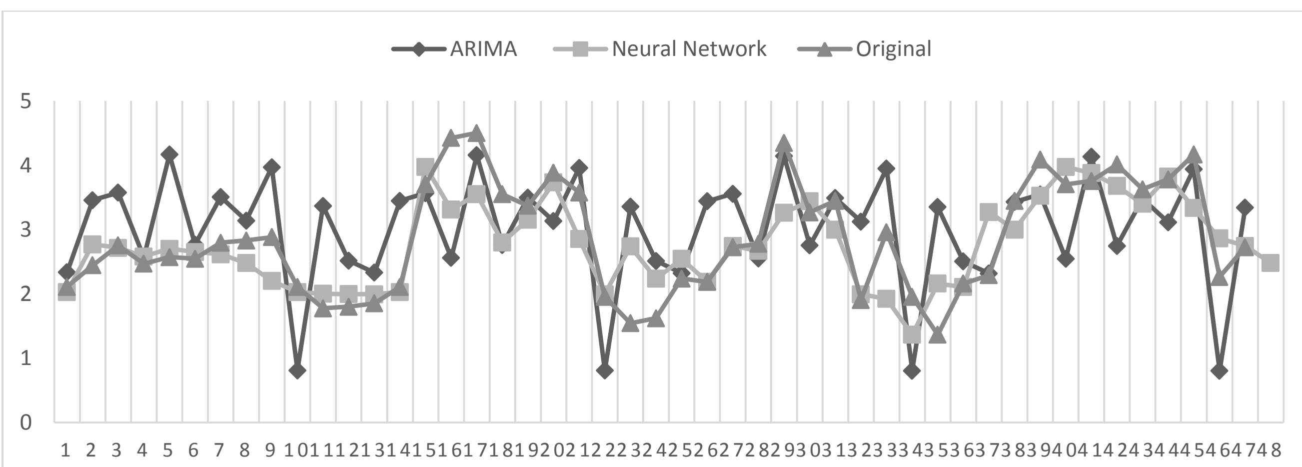

Fig. 25. Comparing the forecasted series obtained using ARIMA models and BPLM-NN method

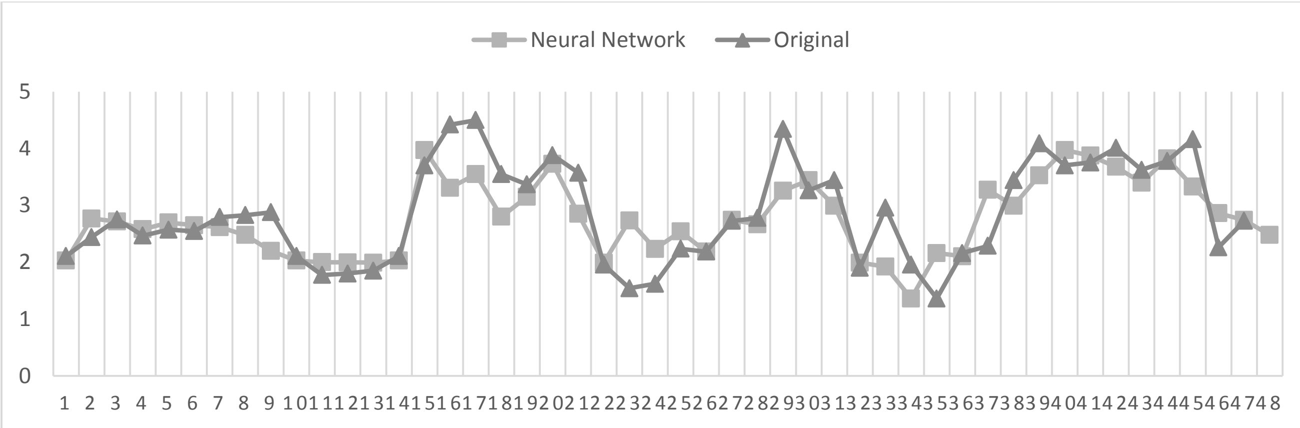

Fig. 26. ARIMA forecast vs original time series

On the other hand, ARIMA clearly failed to capture the trend providing many peaks as shown in Fig. 9.

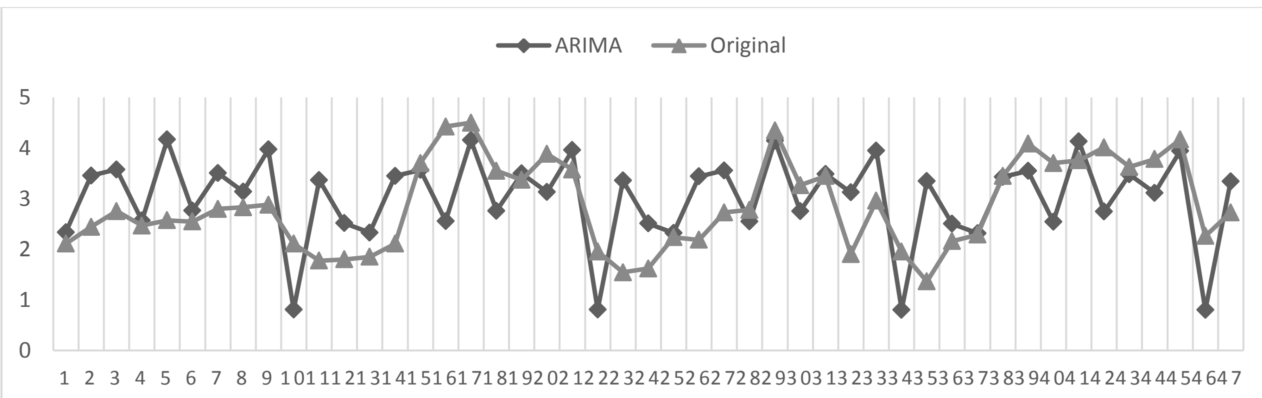

Fig. 27. Neural networks forecast vs original time series

The better performance neural networks can be attributed to their flexible nonlinear modeling capability. With ANNs, there is no need to specify a particular model form. Rather, the model is adaptively formed based on the features presented from the data. The average speed from the ARIMA forecast at 9m was 3.0m/s with a difference of 5.2%. The average speed from the neural networks BPLM method was found out to be 2.76 m/s, a difference of 3.15% from the original series. In addition, a difference of 8% was observed between the forecasted ARIMA values and NN values. Previous study for Ormara, Balochistan indicated more coherence among the two models [28].

Results

	Target Values	MSE	R
Training:	35	1.76741e-1	8.08521e-1
Validation:	7	7.76508e-1	5.17386e-1
Testing:	7	7.77347e-1	8.17503e-1

Fig. 28. BPLM Training results with delay value as 1 and hidden neuron number

TURBINE SELECTION AND WIND POWER GENERATION

For wind power generation, Wind to Energy's turbine with capacity of 3000 kW was chosen. To find out the actual power generation, it is necessary to consider the power curve of selected turbine as shown in Figure 12.

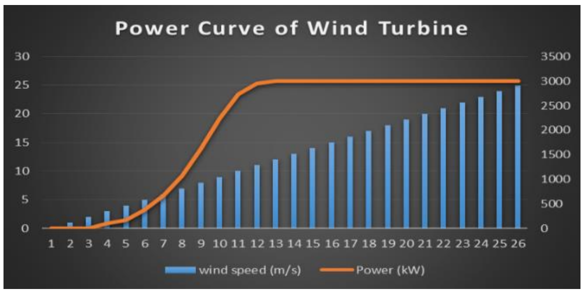

Fig. 29. Power curve of the Fuhrlander 3MW wind turbine

It indicates how much the wind power can be extracted from wind turbine. It is assessed by an anemometer located at locked to wind turbine in areas with low turbulence intensity.

The selected wind turbine has a cut in speed of 3 m/s and cut out speed of 26 m/s. A wind turbine capture its energy by part of kinetic energy of the wind that goes through swept area of the rotor and convert the force into torque acting on the rotor blades. In the range between the cut in speed and rated speed electric power is generated is a function of cube of wind speed.

$$P = 0.5\rho A_r C_p \eta V^3$$

Where,

ρ = air density 1.184 kg/m^3 at 25^o C

A_r = rotor area

C_p = aerodynamic power coefficient of rotor

η = efficiency of generator i.e. 97%

As wind profile gets smoother and smoother at high altitudes. At 100 m height we get best wind profile so we estimated the wind speed for 100 m using wind power profile law taking surface roughness 0.20.

The wind speed obtained from the forecast, as mentioned in Table 1, was used to estimate wind power generation and financial analysis.

FINANCIAL ANALYSIS

To utilize the wind speed of Pasni, Balochistan a hypothetical case study was done. The investment cost is 126.735 million US$. It includes EPC cost, Non-EPC cost, Interest during Constructions (IDC). EPC costs breakdown is as follows:

Agreement with turbine developer including nacelle, hub, blades, SCADA system (59.313 million US $))

Transportation till Karachi port and from Karachi port to site (13.847 million US $)

Towers (11.17 million US $)

Civil works (12.876 million US $)

Electrical works (12.340 million US $)

Project management and supervision (4.732 million US $)

Other EPC costs for surveys, maps (1.00 million US $)

Non-EPC cost breakdown is as follows:

Cost of consultants (1.5 million US $)

Administration during construction (0.832 million US $))

Licenses and other legal costs (0.038 million US $))

Insurance cost during construction (1.35% of EPC cost = 1.44 million US $))

Other projects costs (1.872 million US $))

Financial charges (3.129 million US $))

Interest during construction (2.712 million US $))

It is proposed that 80% of the total project cost will be financed through loans from commercial banks. 100% debt will be in foreign currency and be indexed with the current LIBOR rate at 2.88%. Loan period will be 10 years plus 1 year grace period. It has been supposed that loan is to be repaid in quarterly payments and premium/spread over LIBOR is 3.15%. Since, NEPRA has announced an upfront tariff of 13.52 cents per kWh for wind power projects[19] the electricity export rate was set 135.244 $/MWh.

TABLE 1- PARAMETERS CHOSEN FOR CASE STUDY

Parameters	Units	Value
Technical Data		
Study date	-	2015
Useful life	Years	20
Wind to Energy Wind Turbine	MW	3
No. of turbines		17
Swept area of turbine	m^2	11423
Installed Capacity	MW	50
Capacity Factor	%	16.2
Energy Generated	GWh	72.5
Investment		
Total Project Cost	US$ Million	126.735
EPC Cost	US$ Million	115.166
Non EPC Cost	US$ Million	11.569
Losses		
Array Losses		2%
Airfoil Losses		1%
Miscellaneous losses		1%
Turbine Availability		95%

According to the Pakistan's renewable energy policy, the wind speed risk is borne by the purchase. So without considering the wind speed uncertainty, financial analysis is performed and results are given in Table 2. Cumulative cash flow graphs are shown in Fig. 12.

TABLE 2-FINANCIAL ANALYSIS

Parameters	Values
Benefit Cost Ratio (B.C.R)	0.43
Payback Period	14.5 years
Internal Rate of Return (I.R.R)	6%

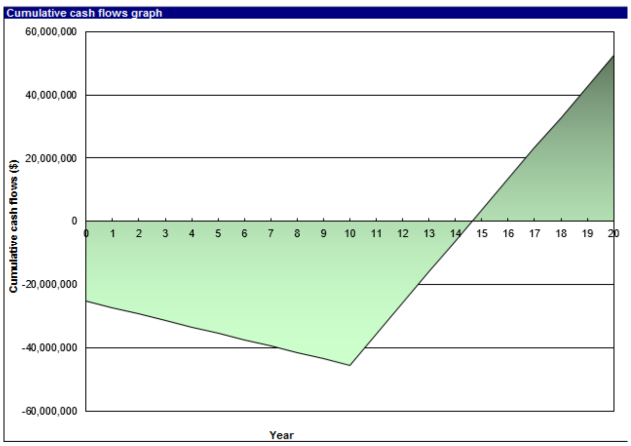

Figure 30-Cumulative cash flows graph showing a break even at 14.5 years

CONCLUSION

Pasni, Balochistan is an average site for wind farm installation. The optimum wind height according to present study is 100m and the appropriate wind turbine is Wind to Energy's 3MW turbine. Increasing the height from the optimum value results in increase in costs without any considerable increase in power output and decreasing the height from the optimum value results in significant decrease in performance. Electricity exported to the grid annually from a 50MW farm at Pasni is estimated as 72510MWh from which an income of 9,806,608 US $ can be generated annually. From investor's viewpoint it is safe but not very profitable to invest in this project according to the financial analysis. This is due a low resource potential at the site.

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Paper D: Review journal paper A review of the wind power developments in Pakistan

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Abstract

Pakistan is among the ten countries that face the worst energy crisis of the world. As the country struggles with a number of financial, political and social issues, the transition from a conventional fuels based economy to a green economy is not an easy one. Pakistan has been blessed with immense potential of clean renewable sources of solar, wind and biomass but they have not been exploited yet. Renewable energy technology sector has not penetrated the energy mix and is currently an emerging market. This paper highlights the steps the country has taken in the past and the steps that are being taken at present to emerge out of the prevailing energy crisis when even the most urban areas suffer from power outages of 12 hours per day. Until 2009, no single grid interconnected wind farm existed but now the situation has changed considerably and wind farms contributing to the national grid are a reality now. Three grind interconnected farms have been inaugurated and many others are in pipeline. This paper reviews the developments in the wind power sector of the country.

Introduction

The global wind capacity touched 336.327 GW by June 2014, of which 17.613 GW were installed in the first half of 2014. This surge is considerably higher than the first six months of 2013 and 2012, during which 13.9 GW and 16.4 GW were installed respectively. The installed capacity of wind turbines is rising at an annual rate of 25% worldwide. This shows a growing interest in the wind electric power every year. Owing to the increase in wind farms in the recent years, around 4 percent of the world's total electricity demand can be fulfilled by the wind turbines [1]. This rapid progress in the recent years is because of declining equipment costs, uncertainty in the conventional fuel prices, government policies and incentives, environment concerns, awareness of green power, need for energy security and increasing carbon risk [2]. During an era of great environmental degradation, a 1 MW wind turbine offers to offset sixty pounds of mercury, fifteen hundred tons of carbon dioxide, three tons of nitrogen oxides and six and a half tons of sulfur dioxide annually. Also, wind power farms generate more power than they consume, between 17 and 39 times, as compared to nuclear plants(16 times) and coal plants (11 times) [3]. Wind power is also related to many social and community issues as well. It has been advocated that increasing energy production through diversification in energy resources has negative relation with poverty and unemployment [4]. It has been predicted that owing to the increasing awareness about their benefits, wind and solar will be the cheapest forms of energy production for largest energy markets of Asia within ten years [5]. Optimistic estimations also estimate that by 2030, one fifth of the electricity demands of the planet can be met by wind energy. This indicates not only environmental but economic benefits for all countries to include wind power as clean, renewable source of energy. This paper attempts to highlight the efforts done in research and development of wind energy sector in Pakistan.

Energy situation in Pakistan

Approximately 1.3 billion people are living without electricity worldwide; 66 percent of them live in ten countries- one of them being Pakistan [6]. Even though energy crisis has plagued Pakistan since its birth in 1947, this national dilemma received attention only in this century. From 1947 to 1980s, domestic resources could meet only two-thirds of the energy demand [7]. As the population increased drastically in 1980s, with annual growth rates more than 3% throughout the decade, Pakistan was struggling to shorten the wide gap between rising demand of energy and its restricted supply. The energy consumption per capita also progressed from 193 kWh in 1985 to 256 kWh in 1989, widening the gap between supply and demand [8]. It was vital to balance the energy supply and the rising needs with an evolving economy and a high population growth rate. Later on, in the early 2000s, the power sector received much attention, reason being the acceleration in the growth rate of electricity demand. In 2008, when industrial consumers were already suffering financial crises caused by shortage of supply of electricity to run their facilities, the then government announced a 75 percent increase in the commercial tariff from 8-10 rupees per kWh to 14 rupees per kWh. Tariff for domestic use was also increased from 5-7 rupees per kWh to 8-10 rupees per kWh. Karachi Electric Supply Company, the main electricity provider to the twenty million people of Karachi, was then suffering an overwhelming financial crises and expressed its inability to supply electricity using furnace oil [9] . During 2011-12, power outages reached 8 to 10 hours daily in metropolitan areas and more than 20 hours in the countryside affecting economic growth [9]. The total shortfall of more than 6000 MW was the primary reason behind restricted industrial production activities. Particularly, Energy exhaustive industries of Iron and Steel, Petroleum, Engineering Industries and Electrical decreased 0.2 percentage points from real GDP growth in fiscal years of 2010-11 and 2011-12 [7]. As the total output of the energy intensive sectors decreased, overall welfare of the country was affected [10]. Now in the recent year, the price of crude oil dropped to almost half of its previous price, from 11,298 rupees per barrel in December 2013 to 6, 112 rupees per barrel in December 2014 [11]. Also, Pakistan's energy statistics from 2012 estimate that an annual electricity consumption of a meagre 74 billion kWh consumption per capita is 456.64 kWh, one of the lowest in the world [12]. Still, Pakistan has been unsuccessful in fulfilling its energy demand by conventional fuels and remains among the ten most energy deficient countries in the world. The current distribution system is not capable of supplying more than 15,000 MW. In effect, the constricting bottleneck currently is distribution and not generation as shown in Fig. 1. Therefore, even if existing generating units are geared up to operate three-fourth of their capacity, the country simply does not have the infrastructure to distribute this power to end users [13]. Hence, the total installed capacity in Pakistan is greater than the actual generated power while the actual generated power is less than the demand [14].

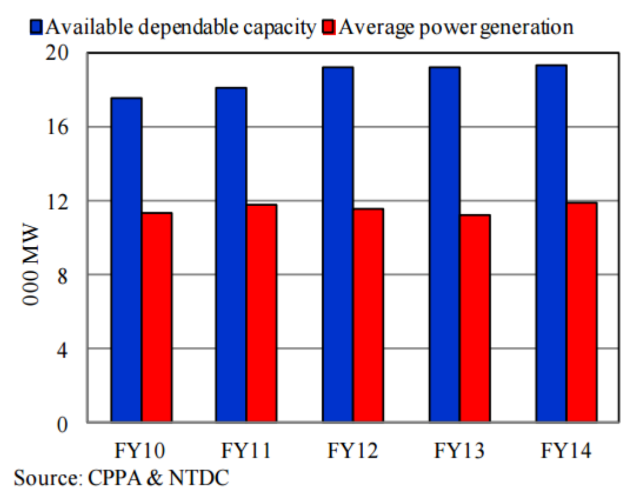

Figure 31- Available capacity and power generations in past 5 fiscal years (FYs) [13]

The gap between supply and demand continuously increased over the years until it reached the prevailing levels. Over all, literature surveys and studies indicate that in past years, Pakistan has been unsuccessful in meeting the rising energy demands for many reasons, including an overreliance on fossil fuels (64.2%), climatic changes, growth in oil prices, insufficient contribution of alternative sources (29 % hydropower and 5.8% nuclear) and not enough technological advancements [9][15][16]. Renewable energy options are becoming increasingly attractive as the country suffers from energy crisis with power outages reaching 12-16 hours per day even in the most urban parts of the country. Literature has shown that in Pakistan, the energy consumption and industrial production and economic expansion are interrelated and power shortages may slow down the country's economic growth [17][18][19]. This explains the low human development index (~0.5) and economic growth of Balochistan, a province that forms 44 percent of the total land mass but only 10 percent population in the province has any access to electricity. By diversifying its energy sources through solar and wind resource gifted by nature, Pakistan can not only attain energy security but also eradicate poverty and empower its people [4].

Initial research efforts

The drive to reform Pakistan's power and energy sector began in the 1980s when country wide power outages weakened any chances of economic development in the country and had crippled the nation. To address this crisis, the government of Pakistan in 1985 enacted its first private power policy. This policy was aimed at bringing private investors to the power sector. Before this policy was enacted in Pakistan, power generation was entirely state-owned and operated monopoly [20][21]. The need for renewable energy was realised by researchers and studies on resource potentials had started in 1980s. Initially, there was a lack of complete and reliable data on wind energy resources in Pakistan. The limited data collected by the wind measuring instruments at different airports of the country was insufficient to determine technical and economic feasibility of wind power projects. Nonetheless, a vague idea of possible sites for harnessing wind energy formed. Raja and Abro held that two-third of the country's land area consists of arid or semi-arid regions which are ideal sites for hybrid solar-wind energy systems because of high percentage of clear days and strong winds. The main city of Baluchistan, Quetta was highlighted for its abundance of solar energy as studies indicated that maximum solar energy was being received by Quetta valley [22]. At the same time, the pros and cons of renewable energy options were discussed by Ghaffar who opined that, for Pakistan solar and biomass were more feasible options as compared to wind energy as winds in the region were a low quality resource and suffered from abrupt variations [23]. Research on wind speed time series in Baluchistan started in 1980s when speed frequency curves, daily variations and speed duration curves were first analysed for the hourly wind data of Quetta. The need to apply mathematical modelling and numerical analysis for wind resource assessment in Pakistan was also highlighted [24]. By this time, it was already established worldwide that the variations in all the basic meteorological can be mathematically represented and wind speed variations can be identified and predicted using mathematical formulations [25]. Realising the need of applying statistical and mathematical models to predict wind speed time series, Jafri et al in 1996 applied ARMA models and found them suitable for prediction intervals and probability forecasts for wind speed time series of Quetta, Baluchistan [26]. Recently in 2012, this was followed by the wind speed time series forecasting using fuzzy logic time series prediction. The prediction was found to be reliable and precise [22][27][28].

Ironically, the sites of coastal areas of Sindh and Baluchistan, where wind speeds are being analysed and energy resource potentials are being discovered, are the same locations which suffer the worst energy crisis since forever. At least half of Sindh's population and nine tenth of the population of Baluchistan has no access to electricity and use kerosene to light their homes. Low population density and small scattered loads make centralised grid system technically and economically unfeasible in these areas. As a solution to this problem, Memon et al proposed domestic wind systems for rural coastal areas. A small wind turbine could generate 350kWh and 250kWh annually in Sindh and Baluchistan respectively, enough for a rural household [29]. Later in 2011, a research indicated that biomass and wind energy are the preferred alternatives and no single renewable energy technology or conventional fuel is the answer to the energy scarcity of Pakistan and a mix of different renewables is required [30].

Steps taken for utilisation of wind energy

The wind energy technology in Pakistan's energy market started its course at a slow pace. The first known windmills used for pumping water and grinding grain were developed in Iran around 500-900 A.D. Being an immediate neighbour of Iran, its only surprising that Pakistan's ancient history is silent about the presence of wind energy technology. It was not realised until recently that the windy mountainous regions and the 1080km long border with Arabian Sea could be used for installation of wind farms. It is reported that first efforts to identify ways of utilization of wind energy were made in 1980s [31]. In 1990s, two units of 10 kWh and 1 kWh were installed in Sindh and Balochistan respectively [32] . Pakistan Council for Appropriate Technology (PCAT) set up more than 12 windmills for water pumping at Sindh and Balochistan. A report on country wide wind resource mapping was submitted to PCAT in March 2001, based on data provided by Pakistan Meteorological Department collected for over fifty years. This report was based on data recorded at fifty stations in the country at an elevation of 2 – 10m. Projected wind speeds were obtained for 30m height showing promising wind energy potential. In another report, parts of Sindh i.e. Chor, Badin, Hyderabad and Karachi were listed as finest locations for wind energy utilization. Also in 2001, a project was initiated by Ministry of Environment and supported by Global Environment Facility, Nordic Trust Fund and United Nations Development Programme under the name of 'Commercialization of Wind Power Potential in Pakistan'. This project was aimed at determining the feasibility of a wind power project at Pasni along the Makran coast, Baluchistan. Unfortunately, this project ended with no outcome because of lack of wind data and incentives. However, valuable recommendations regarding tariff, policy framework and legalities were given which pave the path for wind projects in the future [20],[33]. In 2002, 14 small wind turbine generators (WTGs) were bought from China and set up by Pakistan Council for Renewable Energy Technologies (PCRET) for demonstration purposes. Among these, 8 WTGs were fixed in the coastal regions of Balochistan and six WTGs were erected at coastal sites in Sindh. It was perceived that small wind turbines are feasible for rural electrification in coastal areas [31]. By 2004, a New Zealand company had completed a hybrid wind-diesel project successfully for rural electrification in a village at Sibbi, Balochistan [28][32]. In a study conducted during 2004 – 2007, wind data was measured at twenty sites of Sindh coast [34]. By international standards, four locations of Sindh, Jamshoro, Nooriabad, Talhar and Kati Bandar, were regarded as excellent sites and four locations of Sindh- Thana Bulakhan, Hyderabad, Gharo and Thatta were considered good sites for wind power generation [35].

During the fiscal year 2005-06, as knowledge and awareness in renewable energy sector increased, Government of Pakistan made some plans for the development of wind power sector. Guidelines were given to the Ministry of Water and Power's Alternative Energy Development

Board (AEDB) under the Energy Security Action. Those pertaining to wind energy have been mentioned here:

Wind and solar resources will contribute at least five percent (~9700MW) in the total power generation capacity of the country by 2030

A wind power project of capacity 100 MW will be set up in two towns of Sindh (Keti Bandar and Gharo) which will be upgraded to 700-MW by 2010 [36].

In June 2005, PMD in financial collaboration with Ministry of Science & Technology (MoST), accomplished the first phase of its project "Wind Power Potential Survey of Coastal Areas of Pakistan". In July 2005, second phase commenced which was wind resource mapping for northern areas of the country. The potential areas found along the Sindh Coast include Jamshoro, Hyderabad, Nooriabad, Gharo, Kotri, Thatta, Matli, Talhar, Keti Bandar, Shah Bandar and Mirpur Sakro. The potential areas in Baluchistan include Gwadar, Liari, Chowki, Hub, Jiwani, Pasni, Gadani and Ormara. It was also established that the coastal areas in Sindh have better quality resource Balochistan's coastal areas. The windier areas cover an area of 9,700 km^2 in Sindh. The potential wind power of this area was determined to be 43,000 MW while the technically feasible potential was determined to be about 11,000MW. A feasibility study was prepared for an 18 MW model project and the payback period was calculated to be 7-8 years [28][37]. This was also mentioned in a 2009 report by Asian and Pacific Centre for Transfer of Technology of the United Nations that PMD had launched measurement of wind parameters in the northern areas of Pakistan after completing its six year project of wind data acquisition for the coastal sites of Sindh and Balochistan. According to this report, the actual land used in wind power generation is very small in terms of area, 2-3 percent of total area encompassed by the wind farms. Low height cultivation and cattle grazing can be done in the rest of the area. However, in Pakistan nearly all windy sites are situated in barren areas where cultivation is not a choice, hence the best utilization of the land is wind farming in those areas. The potential wind farming areas in the four provinces of Pakistan for the wind farming are Hyderabad, Keti Bandar and Gharo in Sindh, Mardan in NWFP, Kalar Kahar in northern Punjab, Makran, Kolpur, Nokundi and Chaghi area in Balochistan. [36].A major breakthrough in the development of renewable energy sector as a whole and wind energy in particular was the implementation of first renewable energy policy of Pakistan in 2006. By August 2006, the AEDB had already delivered

56 Letters of Intent (LOIs) for installing wind power projects of different capacities which were followed by more investors later on, increasing the count of the proposed projects to 97. Some of these firms later were either disenchanted with the idea or did not have the required capacity to pursue the opportunity [38]. The Renewable Energy policy 2006 was not immediately successful and faced a number of challenges but nonetheless it was the first big step to green power [21]. By this policy, the wind risk was to be tolerated by the central power purchaser to immune the project developers and investors to the variability of wind resource. This policy also ensured full purchase of electricity from wind farms and offered many attractive fiscal incentives such as exemption from import duties and taxes and income taxes [30]. Soon after, the results of wind resource assessment and mapping done by National Renewable Energy Lab in association with PMD and USAID were published for Afghanistan and Pakistan. Sophisticated mapping techniques using the Geographical Information System software indicated the regions and their energy potential as shown in Fig. 3. Fig. 4 and Fig.5 show the stations for wind data measurements. According to this study the total exploitable potential of wind resource in Pakistan is 132000 MW as shown in Table 1 [39].

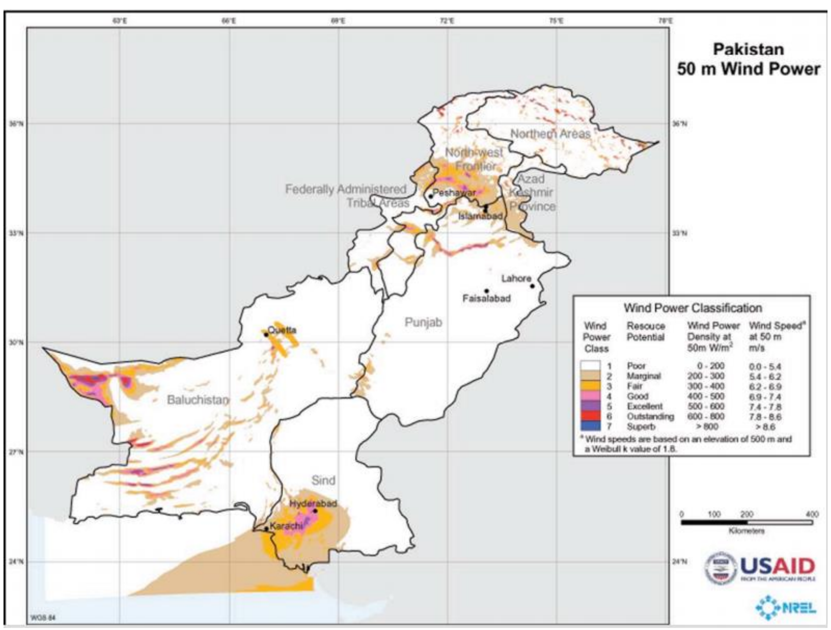

Figure 32- Wind power mapping for Pakistan[39]

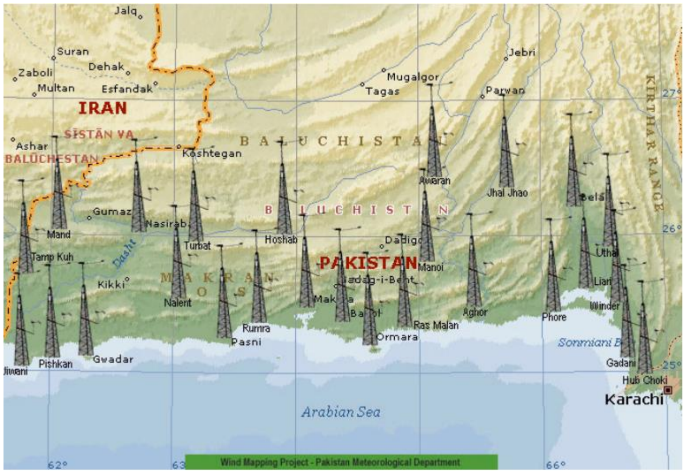

Figure 33- Wind measurement from towers in Balochistan [39]

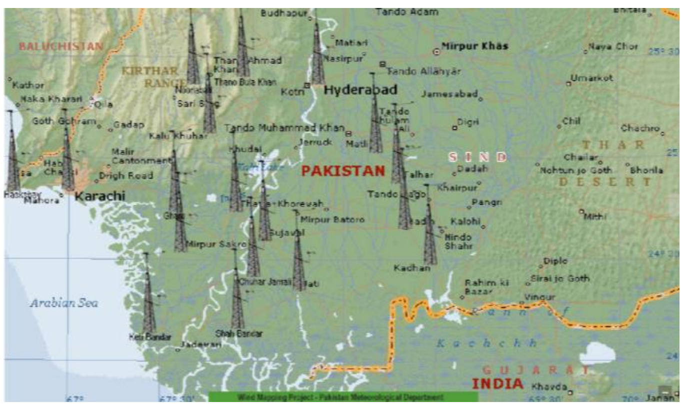

Figure 34- Wind measurement from towers in Sindh [39]

Table 7- Good to Excellent Wind Resource at 50m in Pakistan [39]

Wind resource quality scale	Wind class	Power (kW/m^2)	Speed (m/s)	Area (km^2)	Capacity (GW)
Good	4	0.4-0.5	6.9-7.4	18,106	90.53
Very Good	5	0.5-0.6	7.4-7.8	5,218	26.09
Excellent	6	0.6-0.8	7.8-8.6	2,495	12.48
Excellent	7	>0.8	>8.6	543	2.72
Total				26,362	131.8

Assumptions:

Capacity installed per km^2 is 5 MW. The land area of Pakistan is 877,525 km^2 and offshore area is not included.

In 2007, The EU Asia Invest initiated a European Union funded program for solar, wind and small hydro projects in Pakistan. The aim was to enhance private investment for selected renewable energy technologies including wind power. By 2008, there was no single grid connected wind farm however steps to have some had started. A short term plan was formulated for 2009-2014 in which three clusters of wind farm were proposed in three areas of Sindh, Jhimpir, Kuttikun and Bhambore allocating lands to 23 developers, for 50MW each. Transmission facilities were analysed to ensure smooth grid integration of these wind farms. It was stated in this plan that there are no technical constraints in bringing 500-700MW wind power on board in terms of load flow, dynamic performance and power quality in the three areas of interest in Sindh [40]. During 2008-09 masts were installed at three areas in Sindh namely, Baburband, Keti Bandar, Hawksbay. The wind energy potentials of these areas were analysed and Baburband was marked as a great site for wind power production in the 2010 annual report by AEDB [41]. During 2006-2009, 135 units of micro wind turbines were installed at Sindh providing electricity to 1,431 houses by a generation capacity in excess of 151kW. Gul Muhammad village is reported to be the first village of Pakistan electrified to be provided wind electric power by setting up 26 units of 500W capacity each. In Lasbela, guard check posts were wind-powered and wind powered battery charging facilities were set up in villages. AEDB established a 4MW grid interconnected wind power station at Gharo, Sindh in 2009 – the then biggest installation of the country. AEDB also set up forty small wind turbines in Karachi and 500W micro wind turbines in universities of Balochistan for research on wind power. In 2009, US Secretary of State announced US support for the project entitled “Pakistan Power Distribution Companies (DISCOs) Performance Improvement Program (PDIP)”. The objective of the program was to improve the electricity supply, ensure the operational and financial health of the power sector and take appropriate steps to make the power sector self-sufficient. The absence of smart metering in Pakistan and the need of sophisticated technology to reduce losses during transmission and distribution was highlighted. Funds are being offered by USAID to install required technology [42].

In 2011, Government of Pakistan passed the Alternative Energy Development Board Act, 2011 which empowered AEDB to develop plans and policies for renewable energy utilization in the country and to evaluate and certify renewable energy projects. AEDB was also instructed to act as the middle-man while interacting and coordinating with national and international agencies for renewable energy technologies [43]. Also the previous policy of 2006 was replaced by Alternative and Renewable Energy Policy of 2011. It was reported in the Act that Pakistan has an estimated wind power potential of 346 GW out of which around 60-70 GW is technically exploitable [43]. The target by government given to AEDB of a minimum five percent contribution in national energy mix through wind and solar sources by 2030 was reinstated [43].

Wind Turbine Manufacturing/Assembling Facilities

No large manufacturing company or facility exists in Pakistan that can manufacture all parts required in a wind farm and wind turbines are not available on immediate demand in the global market. One of the reasons is that some countries e.g.United States offer attractive rebates and discounts to manufacturers therefore all top notch manufacturers of wind energy equipment are fully dedicated in supplying to the American market. Through extensive marketing efforts, AEDB claims to have reserved equipment from leading manufacturers, Gamesa of Spain, VESTAS of Denmark and Fuhrlander in Germany and GE of USA, to supply the apparatus needed in Pakistan. Local manufacturing of 500-Watts wind turbine under transfer of technology from China has been reported [36][28].

However, as the demand for wind energy technology is increasing some small companies have begun operation. Marine Private Limited in Karachi is making windmills for lifting up to 22 thousand gallons per hour of water seventy feet deep. The three types of windmills made by this company are Mojahid, Zorawar and Jawana, having a blade diameter of 10, 15 and 20 feet respectively. Engineering Concern Private Limited and Agro Tool Private Limited are developing windmills for lifting water and generating electricity. Pak Wind Energy Limited, Karachi have windmills with a capacity ranging from 1 kW to 15 kW. Quetex International, Karachi manufacture windmills with a capacity ranging from 0.5 to 20 kW. Grace Accumulators, Karachi build windmills with a capacity ranging from 1kW to 5kW. Euro Tech, Karachi have windmills with a capacity ranging from 0.5kW to 2 kW. Energen Energy Generation have windmills with a capacity ranging from 0.5 to 1.00 kW [36].

A 2012 study surveyed the Technology Readiness Level (TRL) of wind turbine blades facilities in Pakistan and concluded that Pakistan’s composite manufacturing units are capable of production of wind turbine blades with little improvements in the available facilities. 62 organizations / manufacturing units are presently involved in composite manufacturing of any nature and level. The technology base of the industry has the absorptive capacity to diversify itself to the wind turbine blades’ manufacturing technology [36].

Institutional Infrastructure

The electricity supply service in the new born Pakistan was offered by both the public and private sector agencies initially. But later on in 1958, to ensure unity and coordination in the sector, Water and Power Development Authority (WAPDA) was formed by the 1958 WAPDA Act. Electricity distribution services in different areas were being executed by regional offices of WAPDA. In 1982, to provide more independence and representation to provincial governments and other interest groups, Area Electricity Boards (AEBs) were set up through the AEB scheme. A total of eight AEBs were established for this purpose. In 1994, by the Strategic Plan for Pakistan Power Sector Reform the power wing of WAPDA was split into fourteen companies for power generation, transmission and distribution of electric power. The purpose was to commercialise and then eventually privatise these 14 organizations, known as generation companies (GENCOs), power distribution companies (DISCOs) and National Transmission and Power Dispatch Company (NTDC) [44]. For wind power projects, a number of other institutions interact with the independent wind power producer to ensure a transparent and productive process.

Alternative Energy Development Board

AEDB was founded in 2003 with the purpose of reducing Pakistan’s dependence on fossil fuels by identifying alternative energy resources like solar, wind, biogas and small hydro projects [45]. The Alternative Energy Development Board Act, 2011 empowered AEDB to develop plans and policies for renewable energy utilization in the country and to evaluate and certify renewable energy projects. AEDB can set up its own projects or through partnership with other firms and provide its technical expertise to the government [42]. AEDB issues Letters of Intent and Letters of Support to competent firms interested in developing independent wind farms after detailed analysis.

National Electric Power Regulatory Authority

NEPRA issues licenses to the power projects for generation, transmission and dispatch of electric power. It forms and imposes standards to safeguard quality and protection during the processing and supplying electric power to end users. It controls investment deals and acquisition of the utility companies and also determines the tariffs for buying, selling and distribution of electric power[46]. An independent wind power production company submits its financial reports that details all project costs according to which NEPRA determines and justifies the tariff that the wind power company can charge for selling electric power. NEPRA determined an upfront tariff regime for wind power projects in April, 2013. The upfront tariff was set to be 13.5244 US cents/ kWh. This tariff is being offered for projects on take-and-pay agreement while the wind risks are borne by the developer unlike the cost plus regime in which the wind risk is borne by the power purchaser. The companies that opt for an upfront tariff are instructed to achieve financial close by a fixed date.

Pakistan Council of Renewable Energy Technologies

Pakistan Council of Renewable Energy Technologies (PCRET) was set up in 2001 by merger of National Institute of Silicon Technology and Pakistan Council for Appropriate Technologies (PCAT). It coordinates research and development activities and promotional events for renewable energy technologies.

National Transmission & Despatch Company Limited (NTDC) Pakistan

National Transmission & Despatch Company Limited was incorporated in November, 1998 and commenced commercial operation in December, 1998. Its main functions are:

procurement of power from conventional fuel power plants and renewables based plants on behalf of distribution companies

protected, safe and dependable operation and control of generation facilities

planning, expansion, operation and maintenance of the 220 kV and 500 kV transmission network

recording and monitoring of contracts relating to bilateral trading system [47].

According to the renewable energy policy, NTDC is bound to purchase the electric power produced by wind power plants at the tariff determined by NEPRA.

A graphical representation of the institutions and their interactions is shown in Fig.6. The Private Power and Infrastructure Board (PPIB)is a state owned facilitator for investors in establishing private power projects and related infrastructure, implements Implementation Agreement with the sponsors and issues sovereign warranties [48]. Pakistan Atomic Energy Commission (PAEC) is concerned with the research and development of nuclear electric power and energy conservation. DISCOs are power distribution companies and GENCOs are power generation companies. As stated earlier, National Transmission and Despatch Company (NTDC) acts as Central Power Purchasing Agency (CPPA) in Pakistan.

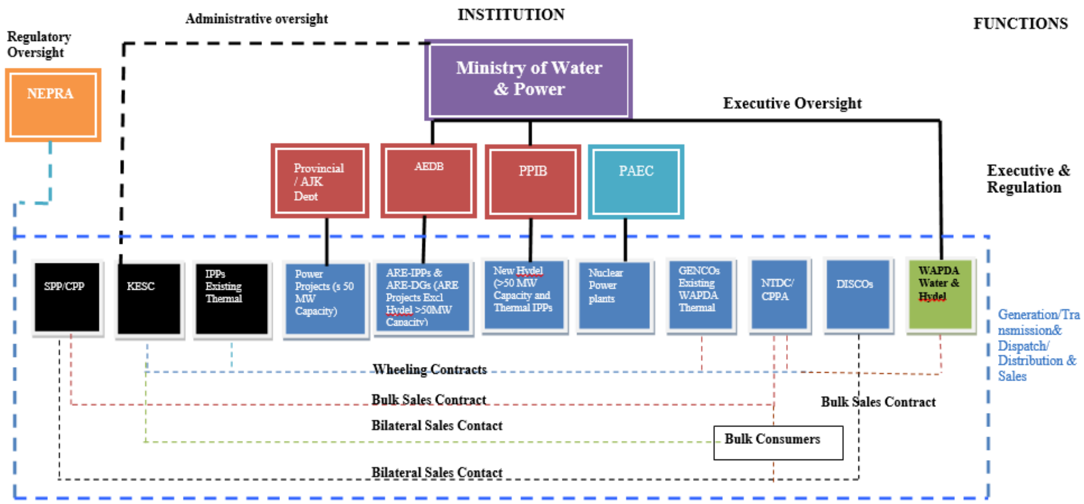

Figure 35-Pakistan's Power sector organisations [43]

Current status of wind power sector in Pakistan

34 independent wind power companies hold Letter of Intent issued from AEDB aiming to develop a total of 1925.4 MW of wind power capacity. After the Letter of Intent is issued, land is allotted by the Land Utilization Department. Letter of Support is issued by AEDB extending its technical expertise for the successful development of the project. Thereafter, generation license and tariff determination is acquired by NEPRA. Energy Purchase agreement is signed by NTDC and the company and Implementation Agreement is signed by AEDB and the company. After these steps have been carried, financial closure is achieved followed by commercial operation of the wind power plant. 15 independent power producers have been issued Letter of Support amounting to 806.4 MW. 3 wind power projects have achieved commercial operation. The details of different wind power producers and their projects is as follows.

FFC Wind Power Project

FFC Energy Ltd.'s wind farm is located in Jhimpir, Sindh occupying an area of about 1,283 acres. The wind farm has been set up at a total cost of US$ 134 million. The grid connection was activated on October 30, 2012. It is now in commercial operation since December, 2012. FFCEL wind farm consists of 33 Nordex S77 of 1.5MW each. The nameplate capacity of wind farm is 49.5MW with a net annual energy production of 143.6GWh [49]. NEPRA has determined tariff of 16.109 cents/kWh for FFC Energy Ltd [50].

Zorlu Energy Project

The wind farm is located at Jhimpir , Sindh . It was established by Zorlu Energy Pakistan, which is a subsidiary of Zorlu Enerji. The investment on this project was US$143 million. Initially, 62 Vensys turbines of 1.2 MW each were installed in April 2009. Later on, 28 Vestas turbines of 1.8 MW capacity each were installed increasing the total capacity of the wind farm to 56.4 MW. NEPRA determined a tariff of 13.3456 US cents/kWh for this wind farm [50]. The project was concluded in March 2013 [51].

Figure 36- Zorlu Enerji's wind farm in Jhimpir, Sindh [52]

Three Gorges First Wind Farm Pakistan

The wind farm developed by a Chinese company is located in Jhimpir, Sindh. US $130 million was spent to develop this 49.5 MW wind power project recently inaugurated on 11th March, 2015. 33 Goldwind's turbines GW771500 were used. Plans to increase the plant capacity to 500MW have also been reported [53]. NEPRA has determined a tariff of 13.9399 cents/kWh for this wind power project. The timeframe of these three IPPs is given in Table 2.

Table 8- Timeframe of completion of three wind power projects in Pakistan [50]

Independent Power Producer	Location	Capacity (MW)	Obtained Letter of Support (LOS) from AEDB	Acquired generation license from NEPRA	Obtained tariff from NEPRA	Energy purchase agreement with	Implementation agreement	Financial close	Commercial operation
Zorlu Enerji Pakistan Ltd.	Jhimpir	56.4	December, 2010	May, 2011	December, 2011	April, 2011	February, 2011	June, 2011	December, 2012
FFC Energy Ltd.	Jhimpir	49.5	February, 2009	August,2010	August, 2010	January, 2012	April, 2012	May, 2012	July, 2013
Three Gorges First Wind Farm Pakistan Limited	Jhimpir	49.5	December, 2011	October,2011	December, 2011	January, 2013	October, 2012	July, 2013	March, 2015

Foundation Wind Energy Limited (FWEL) Project I and II

Two projects of 50MW each are underway located at KuttiKun New Island, Sindh. The total site land area is 1210 acres for FWEL-I and 1656 acres for FWEL-II. The total investment required for FWEL-I is around US $ 128 million for FWEL-II the investment is around US$ 127 million with debt equity ratio of 75%:25%. Tariff approved by NEPRA for FWEL-I is 14.1359 cents/kWh and for FWEL-II is 14.1164 cents/kWh. The progress of these projects is shown in Table 3.

Table 9- Timeline of Foundation Wind Energy Limited I and II nearing completion [50]

Independent Power Producer	Location	Capacity	Acquired generation license from	Obtained tariff from	Obtained	Energy purchase agreement	Implementation agreement	Financial close	Commercial
Foundation Wind energy Limited- I	KuttiKun	50	December, 2011	March, 2012	May, 2012	December, 2012	December, 2012	July,2013	-
Foundation Wind Energy Limited - II	Kuttikun	50	December, 2011	March, 2012	May, 2012	December, 2012	December, 2012	April, 2013	-

Sapphire Wind Power Project

This wind power project of 50MW over an area of 1,372 acres is underway at Jhimpir, Sindh. General Electric's 33 latest wind turbines are being installed. The project is being sponsored by Sapphire Textile Mills Limited and Bank Alfalah Ltd. The Overseas Private Investment Corporation (OPIC) is also extending financial assistance. Hydro China Corporation is the main contractor for this project [54]. OPIC and Sapphire Wind Power Limited signed the agreement to set up this wind farm in September 2013. The company has opted for upfront tariff regime. According to the most recent information available, the company has signed Implementation Agreement with AEDB in February, 2014 and executed the financing documents for US$ 95 million financing in March,2014 [55] [56].

Yunus Energy Wind Farm

Yunus Energy Limited is fully owned by the Yunus Brothers Group and was established in 2011The site for this project is Jhimpir, Sindh. The company obtained the generation license in December 2011. In November 2013, upfront tariff was approved by NEPRA as opted by the company. On 26th March, 2014, the company signed energy purchase agreement with the central power purchasing authority NTDC. In December 2014, the company announced that it faces 210 million rupees spike amid volatile exchange rate and an increase in other variable costs [38]. The project has not yet achieved financial close.

Sachal Energy Development Project

Sachal Energy Development Limited is a subsidiary of Arif Habib Corporation Limited. It aims to build a 49.5MW power plant in Jhimpir, Sindh by 2016. The company employed the Chinese company Hydrochina Ltd. for engineering, procurement, construction, operation and maintenance services in April, 2012. The construction phase of the project is expected to begin in 2015. It is expected that the wind farm will generate an annual energy of 136,500 MWh and offset greenhouse gas emissions by 85,000 tons annually during operation. Industrial and Commercial Bank of China will provide US$ 107 million for the construction of this wind farm. Under Pak-China Economic Corridor projects, it is the first wind power project to achieve this breakthrough [57]. The company signed the power purchase agreement on 27th February, 2014.The land allocated for this project is 680 acres [58].

Metro Power Project

A 50 MW wind power project of Metro Power Company Limited is located between Hyderabad and Karachi, Sindh. The project achieved financial close in February, 2015 and is expected to start operation in August 2016 [59]. NEPRA announced a tariff of 14.4236 cents/kWh for this project in May, 2012 [55]. The land allocated for this wind farm is 1,553 acres [58].The company executed the financing documents for $ 98.6 million financing of this wind power project in April, 2014 [56].

Gul Ahmed Wind Power Project

Gul Ahmed Wind Power Limited (GAWPL) is a 55% owned subsidiary of Gul Ahmed Energy Limited. Besides Gul Ahmed Energy Limited, GAWPL is also owned by Infraco Asia. International Finance Corporation is also a minority shareholder in the wind project. The company obtained its generation license in December. 2011. The proposed wind farm site is located in Jhimpir. The project is located beside its group company's wind project, Metro power Company Ltd. The plan is to install 20 x 2.5 MW Nordex turbines for its 50MW wind power plant [60]. The area of the project site is 645 acres [58]. The company has opted for upfront tariff of 13.5244 cents/kWh [55]. The company signed energy purchase agreement with National Transmission and Despatch Company Limited on March 20, 2015. The company is expected to achieve financial closure in 2015 and start its operation in 2016 [61].

Tenaga Generasi Project

Tenaga Generasi is a subsidiary of Dawood Lawrencepur Limited. The company is installing a 50MW wind power plant at Gharo, Sindh at an estimated cost of US$ 130 million. The project site covers an area of 4,881 acres. The project is expected to generate an annual average of 156 GWh of electricity at 36% capacity factor. The company acquired LOS from AEDB in September 2010 and has opted for upfront tariff.

Master Wind Energy Project

Master Wind Energy Limited is a subsidiary of Master Group. The company secured a letter of intent from AEDB for a 49.5 MW wind power plant in Jhimpir. The company has acquired generation license and tariff from NEPRA under upfront tariff regime. The estimated cost of this project is US$ 125 million. The project is spread over 1,408 acres area. The company acquired LOS on August 08, 2012. It signed the energy purchase agreement with National Transmission and Despatch Company Limited on March 20, 2015. The implementation agreement (IA) to be signed with AEDB has been finalized.The company is expected to achieve financial closure in 2015 and start its operation in September 2016 [61].

Zephyr Power Project

Zephyr Power Limited is sister company of Omega Limited which has been a forerunner in Pakistan's wind data analysis. The company obtained Letter of Support from AEDB in January, 2013 to develop wind farm in Bhambore, Sindh.The Company opted for cost plus regime which was approved by NEPRA at a tariff of 15.9135 US cents/kWh in May, 2012. 33 Sinovel wind turbines of 1.5MW (SL 82 1.5 MW) are to be installed for a total capacity of 49.5MW of wind farm. The company estimates the total project cost of US$ 139.591 million and a net deliverable energy production of 141.763 GWh/year with a net capacity factor of 32.7%.

Hydrochina Dawood Power Project

The company obtained Letter of Support from AEDB in June, 2010 for developing a wind farm near Port Qasim, Bhambore Sindh. In June 2013, Hydrochina Dawood Power (Pvt) Limited obtained the power generation license for operating the wind power plant with 33 turbines of 1.5MW Goldwind wind turbines but later in November 2014, the company stated that wind turbines of Guangdong Mingyang Wind Power Group Co. Ltd. are more suited to the site conditions. The anticipated date of project commissioning is June 30, 2016. The company has opted for upfront tariff regime.

Tapal Wind Energy Project

Three leading business houses,- Akhtar Group, Tapal Group and Ismail Group are setting up a 30MW wind power project over a land area of 200 acres in Jhimpir [62]. The company acquired generation license in November, 2013 for its wind farm. The company also obtained the approval for upfront tariff in November, 2013 from NEPRA. It has signed the energy purchase agreement with National Transmission and Despatch Company Limited on March 20, 2015. The company is expected to achieve financial closure in 2015 and start its operation in 2016 [61].

Other Projects

Some other projects have started and are at various stages of development.

UEP Wind Power Pakistan (Pvt) Ltd has obtained Letter of Support from AEDB for a 100MW wind power plant in Jhimpir and also acquired generation license from NEPRA in November, 2013. It holds a Letter of Intent from AEDB for 350MW wind farm which indicates tentative plan of expansion in future. Hawa Holding Limted acquired generation license in January, 2013 for its 50 MWwind farm in Jhimpir. The company has opted for upfront tariff. Finerji (Pvt) Ltd acquired generation license in August, 2013 for its 50MW wind farm in Jhimpir. Dewan Energy Ltd. has been allocated land in Jhimpir for a 50MW wind farm and has opted for upfront tariff. Titan Energy Pakistan (Pvt) Ltd has opted for upfront tariff for its proposed 10 MW wind power project in Jhimpir. Paksitan Wind Energy Generation Company Limited is building a 5 MW wind power project. Hartford Alternate Energy's 50MW wind farm, China Sunec Energy (Pvt) Ltd's 50MW wind power project, Tricon Boston Corporation's three wind power plants of

50MW each, Trident Energy (Pvt) Ltd's 50MW wind farm and Wind Eagle Ltd.'s two projects of 50MW over an area of 1382 acres each have been allocated lands to develop wind power projects in Jhimpir. Apart from these two projects by Abbas Steel Group, Zaver Petroleum Corporation Limited of 50MW each have been issued Letter of Intent by AEDB. Burj Wind Energy Limited and Western Energy have also initiated the process of developing wind power projects of 14MW and 15MW respectively [55]. Land has been allocated to NBT Wind Power Limited of 1209 acres for its 500MW proposed wind power plant. Fina Energy Limited has been allotted 424 acres for its 50 MW project. Ismail Power Limited has been allotted 69 acres and Akhtar & Sons Group has been allotted 62 acres for their 10MW projects. Iran Pak Wind Power Limited have been issued 1,250 acres of land for its 50 MW wind power plant. Some companies are awaiting land allotment such as Sindh Renewable Energy Company and Hydro China XIBEI Engineering Corporation require 1,000 acres of land each for their100MW wind power plants. Two other companies Koonj's project of 30MW and Tawa's project of 20MW require 150 acres and 100 acres of land for their wind power project.

Conclusion

Renewable energy is an emerging market in Pakistan. Although wind power was slow to enter Pakistan's energy market but the past six years have seen tremendous growth in the wind power sector. At a quick pace, 3 grid interconnected wind farms have been added to the national grid contributing more than 150 MW. Besides these projects, many other projects are at different stages nearing completion. This has been due the strengthening institutional infrastructure, fast track processing of proposals, foreign and private sector's investment and attractive renewable energy policy of 2011 for the wind power developers. It is expected that in the next five years, wind power will contribute at least 2 GW electric power and help Pakistan achieves its aim of 5% contribution of renewable energy in the national energy supply by 2030. Efforts for smart metering are underway which will expedite the growth of renewable energy sector.

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