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# MODELING OF THE WIND POWER PLANT

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## Abstract

The growing demand for energy coupled with dwindling fossil fuel reserves, escalating environmental degradation stemming from their combustion, the repercussions of global warming and the greenhouse effect, the issue of acid rain, and the imperative to mitigate CO2 emissions underscore the urgency of conserving fossil fuels and prioritizing renewable energy sources. Wind energy stands out as a significant form of renewable energy that has long captured human interest, prompting continuous exploration of its industrial applications. Throughout history, humans have utilized wind to propel boats, sailing vessels, and windmills. Considering the contemporary context encompassing the aforementioned challenges and the economic viability of wind energy compared to other energy alternatives, wind energy emerges as indispensable. This article begins with an overview of suitable locations for wind turbine installations within power systems, followed by an exploration of diverse methods for forecasting wind speeds and predicting wind farm power output. Subsequently, the modeling of wind power plants is elucidated, encompassing a comprehensive explanation of various modeling techniques and the associated equations for each model.

**Keywords**: Wind Energy conversion system, Wind power production.

## Introduction

For millennia, humans have harnessed the power of wind as an energy source. Wind energy, alongside hydropower, was among the most widely utilized forms of energy during the seventeenth and eighteenth centuries. Towards the late nineteenth century, initial experiments were conducted to harness electricity from windmills. However, there was a prolonged period where the inclination towards utilizing wind power waned. The global oil crisis of 1972 prompted a widespread return to renewable energy sources such as wind power. Presently, wind power stands as a staple component of the electricity market. When deploying new wind turbines, energy production is not the sole significant factor; considerations such as efficiency, cost, environmental impacts, and grid compatibility are crucial in decision-making processes [1]. Strong political backing and growing public interest in renewable energy have led to a substantial surge in wind power usage, catalyzing advancements in wind turbine technology. It is anticipated that wind power will soon contribute approximately 2% of world’s total electricity demand, with more than 77 GW of capacity, including 7% increment in installed capacity in the last year.

## Concerns of the power system

The positioning of wind turbines within the power system is continuously evolving, particularly due to the significant increase in wind energy capacity. Initially considered small and insignificant local energy sources in the 1980s and 1990s, the unpredictable nature of wind necessitates thorough modeling and forecasting of its impact on the power grid. With the substantial growth in installed wind power capacity and future expansion plans, there is growing concern within the power system regarding its stability. Wind energy is now acknowledged as a substantial energy contributor, prompting increased focus on modeling and predicting wind turbine reactions to the power system's dynamic behavior.

Environmental conditions profoundly influence wind turbines, impacting their output load, useful life, and performance. Considering all environmental parameters is crucial to ensure confidence and safety in selecting optimal turbines. These conditions are typically categorized into normal and harsh winds. Normal long-term conditions primarily affect structural load and operational parameters, while rare occurrences like hurricanes can potentially induce critical conditions [2,3,4,11]. Wind turbines are classified into different classes based on their ability to withstand various wind conditions according to IEC61400-1 Rev2 standards. Before delving into various methods for predicting wind power, it is pertinent to review different models of wind power plants [6].

**Modeling Of Wind Turbines**

The performance and longevity of wind turbines are significantly influenced by environmental conditions, which directly impact their output load and overall effectiveness. To ensure a higher level of confidence and safety in selecting the most suitable turbines, all environmental factors must be carefully considered. These factors are typically categorized into the typical and harsh winds subgroups. [5]. Normal long-term conditions primarily impact structural load and operational parameters, whereas although hurricanes are rare, they have the potential to create critical conditions[11]. Wind turbines are classified into different categories based on their ability to withstand varying wind conditions, following the guidelines outlined in IEC61400-1 Rev2 standards. Before delving into the various methods of predicting wind power, it is essential to review different models of wind power plants [2].

For millennia, humans have utilized wind as an energy source, alongside hydropower. Wind energy was one of the most extensively utilized forms of energy during the seventeenth and eighteenth centuries. In the late nineteenth century, initial experiments were carried out to use windmills to produce electricity. However, there was a prolonged period where the utilization of wind power declined. The global oil crisis in 1972 prompted a large-scale resurgence in the adoption of renewable such as wind power. Presently, wind power stands as a cornerstone of the electricity market. When deploying new wind turbines, considerations extend beyond production of energy alone; factors such as efficiency, cost, environmental impacts, and grid compatibility are crucial. Political backing and growing public interest in renewable energy have fueled a substantial increase in the utilization of wind power, leading to advancements in wind turbine technology. It is anticipated that wind power will soon contribute approximately 2% of Europe's total electricity demand, with more than 77 GW of capacity, including 7% increment installed in the last year installation [1,9,10].

**Modeling of Wind Power Plants**

Many research studies utilize integrated models to simulate wind power plants and sites, given the standardized and interconnected nature of wind turbines. However, when dealing with large wind power plants comprising numerous turbines, integrated models of output power may lack precision. This is particularly evident for wind turbines employing induction generators and controlled stall passive systems, as their output power is highly reliant on changes in wind speed. Furthermore, wind velocity varies across different locations and for different turbines within a site, especially in scenarios involving a large number of turbines spread over considerable distances, leading to significant disparities in output power [6,8].

In contrast, modern technology employs variable-speed turbine concepts, where turbines are connected to the grid via power electronic converters [12]. By controlling the angle of the turbine blades, the input power to the generator can be regulated. This control, facilitated by the blade step angle model, ensures better performance under nominal conditions. Power and receiving the highest power level from attainablewind energy.

Modeling a wind power station considering fluctuating wind speeds over time consists of wind turbine model ,wind turbine and induction generator, capacitor bank and transmission line.

The model is depicted in Fig1.

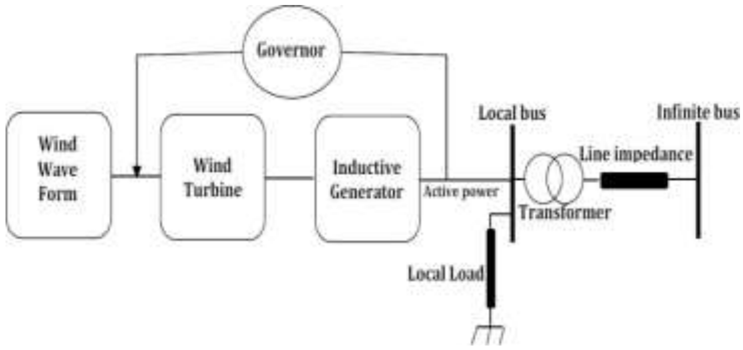


Fig 1. Block diagram of wind power plant

Modelling studied power plants is vital for evaluating their efficiency, whether they are connected to the grid or operate independently. Through such modelling, we can assess their performance in both normal and abnormal conditions, such as faults, islanding, voltage fluctuations, and changes in aerodynamic torque. Moreover, accurately representing the power grid with integrated wind farms is crucial for analyzing the impact of these farms on the grid and understanding the dynamic interaction between them. Over recent decades, a variety of models have been developed for wind power plants to suit specific research objectives. Consequently, this article provides a brief overview of these models and their progression [2].

**Simple Third Order Model**

In Fig 2, which is a third-order model, is one of the most basic models. The variables describing the system's state in this model include the induced rotor voltage, the rotor magnetic flux angle with respect to a selected reference frame, and the rotor speed. Equations representing each induction generator in a power station can be derived by employing a revolving reference synchronous frame. This wind power house model deviates for traditional induction generator models, which usually consist of nine state variables according to Cross, and it does not account for stator transient situations. Furthermore, as these models progress, the stator voltage and current may be estimated directly from the flux and rotor variables.

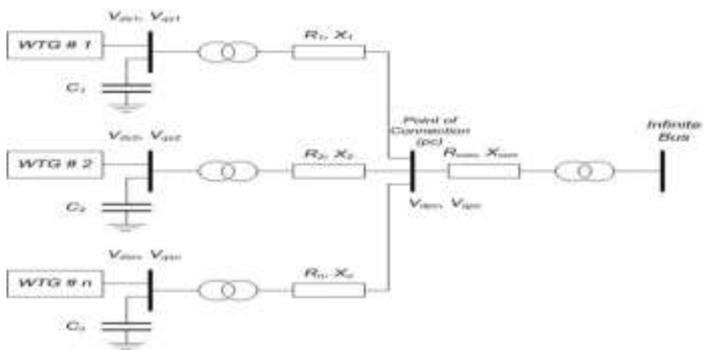


Fig 2. simple third order wind power plant

The circuit layouts suggest that this system functions radially. Therefore, adjustments to the d and q axes are selected to alter the control inputs to the plant, thereby modifying the characteristics of the connected generator. This model is solved using the fourth-order Runge-Kutta (R-K) technique with a time step of 1ms. This model is used to analyze the dynamic behavior of 1MW wind turbines in several scenarios, including sinusoidal variations in the operator's tensional torque, voltage interruptions in the power grid, and the response to changes in frequency. The outcomes of the simplified model are being compared. The simulation results solely demonstrate the performance of a single wind turbine, assuming uniform performance across all turbines. Additionally, this model disregards the aerodynamic attributes of wind turbines, and the turbine model employed solely concentrates on the generator function.

**Active & Reactive Power Model**

In this system the modelled using the output active and the reactive power as state variables. Now if the power plan consists of N no of induction generator connected in parallel. The complete system is considered as a single generator and the total output complex power accompanied by the rotor speed are taken as state variables to model the total power plant. The block diagram for the system is given in figure 3.

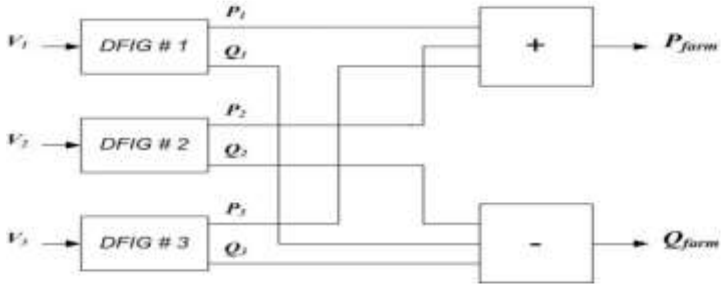


Fig 3 Schematic model of active and reactive wind power plant

The variations are:

- Each generator is subjected to a certain speed where the load is varied as a function of time.
- A sinusoidal wind speed is given thereby varying the magnitude and frequency of the system.

In a separate investigation, the conventional bus PQ model is adapted to depict the power plant. This modification involves computing the active and reactive power of the generator while taking into account the steady-state generator model. It is postulated that the generators utilized in this inquiry are identical and operate inductively. The diagram of the electrical network configuration is illustrated in Figure 4, whereas Figure 5 provides an schematic diagram for this type of power system.

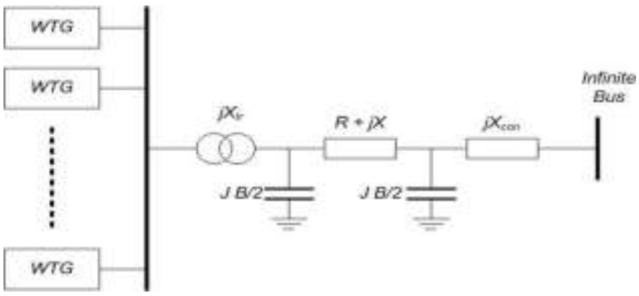


Fig 4. Power System under Study

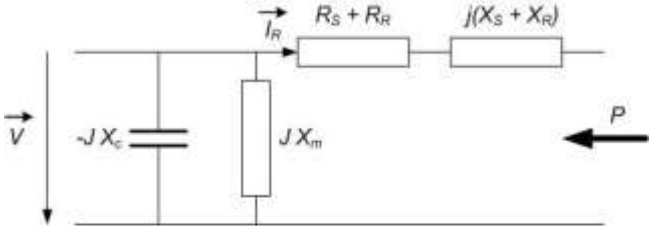


Fig 5. Schematic model of inductive machine.

• If d axis component of the current in the bus is assumed to remain constant, then the reactive power remains constant determined based on the calculations from the first iteration. Thereby making the control loops decoupled and simple.

• If the bus voltage varies, an iterative method such as the Newton-Raphson method is employed, considering terms proportional to the reactive power.
This research introduces an alternative wind power plant model that utilizes the RX bus model instead of the PQ bus model. The algorithm for this approach is outlined as follows.
• It is assumed that the machine slide has an initial value.(usually a notional value)
• The impedance is established.
• The wind power plant is visualized as a PQ bus, with the machinery acceptance being specified in detail by the admittance matrix.
• The first load distribution analysis is used to determine the bus voltages.
Identifying the mechanical output of turbines is achieved through

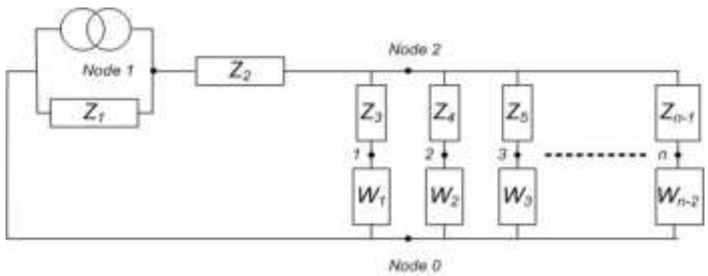


Fig 6 Schematic diagram of power system with a wind power plant

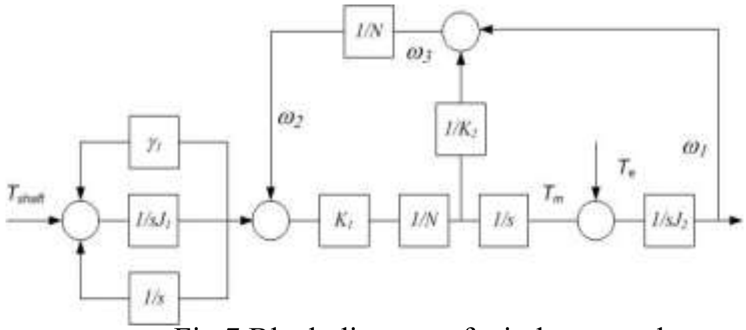


Fig 7 Block diagram of wind power plant

$$P_m = -I_R^2 R_r(1 - S/_S)$$

The two powers are then contrasted. In the event that they are equal, the simulation ends. If not, the slip amount is changed by working out an equation in which the machine's characteristics determine the coefficient J. Additionally, several other assumptions are made: The wind powerhouse is made up of two rows of wind turbines that are placed sufficiently apart to avoid interactions and near enough together to account for the effects of one turbine on the other.
It is assumed that all machines experience the same wind speed when the wind blows perpendicular to the rows of turbines. When there is a parallel wind, the machine facing the wind first in a row determines the wind speed; the other machines in the row are estimated based on this wind speed. State Variable

**Matrix Model**
For the purpose of studying, another model is built. A synchronous machine that rotates in synchronous mode simplifies the power grid in Cyprus. Figure 6 illustrates Node 1 on this computer. Loads are fed along the transmission line by the "Zi+2" impedance and are displayed by wi. The 300 kW HAWTs in the wind powerhouse are powered by induction generators and are displayed by Wn-2. Zn impedance wind powerhouse is linked to the network. The wind turbine is modelled using a

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linear model, as seen in Figure 7. In this model, wind powerhouse density is ignored. For a linear simulation is created using

$$\dot{X} = A1X + A2MX + BU$$

In the equation, U is the system's control input, A1 and A2 are system parameter, X is the state variable, and the flow matrix of the (MX=ΔI_m) line. In order to incorporate several wind turbines, even when exposed to input wind, a model merges them into a single turbine model with a greater nominal power. During the consolidation process, parameters are changed to retain mechanical and electrical properties per unit, with an increase in nominal power equivalent to the total power of the turbines. Compared to detailed models with several turbines and connections, this aggregated model minimizes processing time and simulations. To make sure the model accurately represents reality, though, great thought must be given to the aggregate parameter selection. Additionally,

**Detailed Model**

Figure 8 illustrates one of the comprehensive models for a wind power plant in Denmark that consists of six grid-connected, identical wind turbines, each with a capacity of two megawatts. The turbines have equivalent specifications and operating conditions. This model's goal is to investigate how the Danish power system, both under typical operating settings and in response to power quality factors such reactive power, power variations, and wind powerhouse scintillation, are affected. Models for wind speed, aerodynamics, and the mechanical and electrical parts of wind turbines are all included in this model, along with models for a grid of connected turbines. Inductive generators

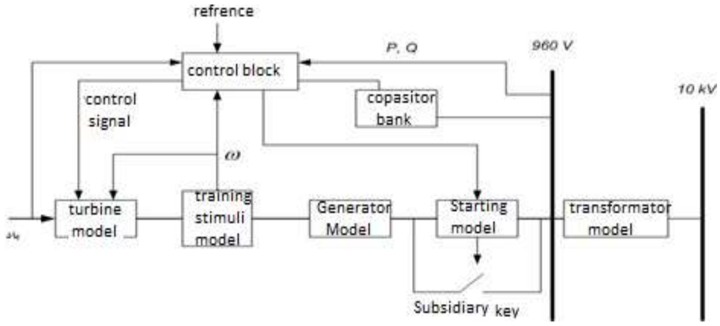


Fig 8. Model of Wind Turbine

There are some operational points at which these linear models are effective. Furthermore, the turbines are supposed to operate under identical conditions, which is unrealistic for a large-scale wind generating plant.

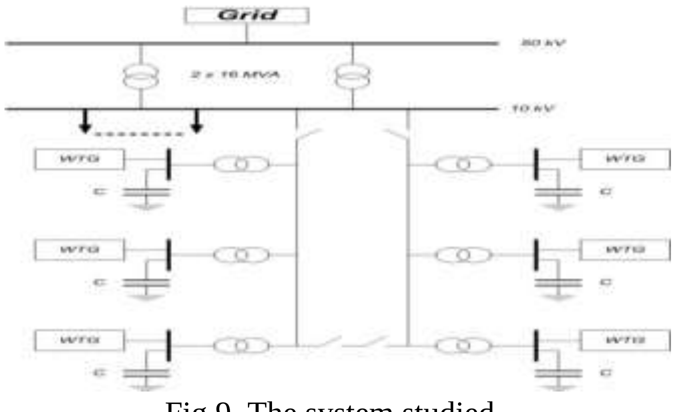


Fig 9. The system studied

To evaluate the wind turbines in the power system, another technique is used. In this case study, a wind farm with 72 identical 2MW wind turbines is being investigated. It is situated on the beach. There are six rows of these turbines, with twelve turbines in each row.

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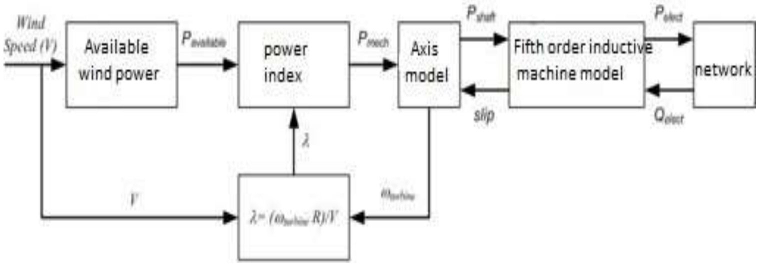


Fig 10. Turbine model of wind power plant

For uncompensated inductive generators, a fifth-order model that includes the wind turbine shaft model is utilized. Two separate hypotheses on wind speed have been studied. Under the first assumption, all wind turbines in the wind powerhouse operate at the same speed of 12 m/s and there is a uniform distribution of wind within the structure. The second assumption takes into account an uneven distribution of wind throughout the wind powerhouse, with wind speeds of 14 m/s in locations where the turbines are directly exposed to the wind and 0.5 m/s less wind orientation from a single group of turbines to the next. Two wind orientations are taken into consideration in the latter case. parallel to and perpendicular to the wind turbine rows. This study compared the performance of wind turbines and evaluated the impact of wind turbine shaft stiffness employing a variety of wind powerhouse models, including detailed, aggregated (multi-machine), and single-machine models.
It should be noted that developing such models for large-scale wind powerhouses poses significant challenges.

**Techniques For Forecasting Wind Speed And Power**

A few examples of the variables that affect wind speed are temperature, pressure gradient, and terrain type. For wind power networks to effectively plan when to activate or deactivate wind farms or conventional generators connected to the network, wind pattern prediction is essential. Costs and the environmental impact are reduced with the aid of this strategic management. Furthermore, modeling the power output of wind farms and resolving issues with balancing electrical power distribution system loads using wind power depend on precise wind speed forecast [4].
In this section, different method for forecasting wind speed and power output of wind farms will be discussed.

Spatial Correlation-Based Methodologies

These methods forecast wind power and speed at stations under review by using data collection and wind speed readings from neighboring stations. This wind energy conversion system involves measuring wind direction and speed at multiple deployed stations nearby, then using wireless modems to send the data to a central computer at the WECS stations. The FES, which determines the spatial relationships between the measuring stations, is subsequently carried out by the central computer. During the training phase, two GA are used and contrasted with the FES. The FES-based wind forecasting methods are shown in Figure 11.

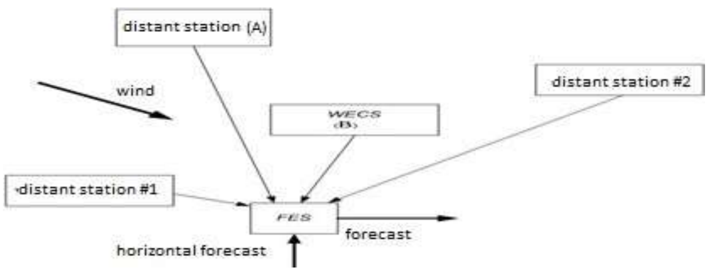


Fig 11. Wind Forecast System

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Other methods utilizing artificial neural networks have been created to predict the electrical power output and wind speed for wind energy systems several hours ahead, simplifying the process.. In order to create the ANN model using this method, measurements are taken at stations that are anywhere from 0.8 km to 40 km apart.

More recently, sophisticated phased models and local recurrence neural networks have been created as improved spatial dependence techniques to predict speed and power at least 36 hours ahead of time. For these models to produce a comprehensive and reasonable prediction, data must be gathered from several sources. Furthermore, as these methods depend on wind direction, precise wind direction forecasting is essential to their efficient use in wind power prediction.

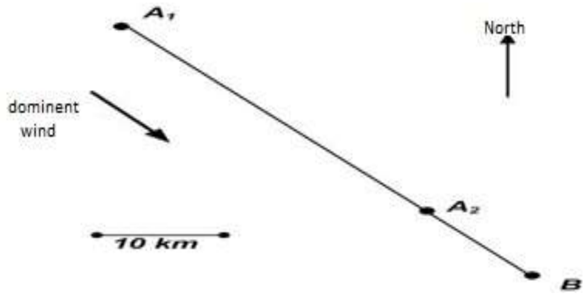


Fig 12. Site with great distances

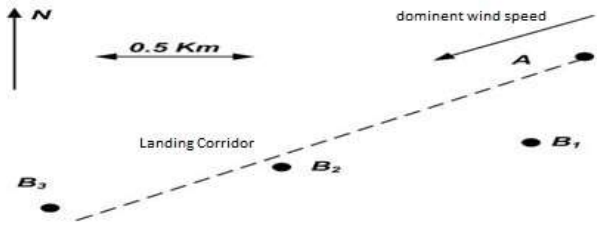


Fig 13. Location of shorter ranges Techniques Utilizing Time Series

Auto Regressive (AR), Auto Regressive Integrated Moving Average (ARIMA) and Auto Regressive Moving Average (ARMA), time series models are used to forecast wind speeds. Furthermore, time series models that utilize Artificial Neural Networks (ANN) are utilized to predict wind speed. Models like the Neural Logical Network (NLN), Adaptive Network-based Fuzzy Inference System (ANFIS), Radial Basis Function network (RBF) and Elman Recurrent Network (ERN) are frequently utilized within this area.

For the purpose of calculating model parameters and preparing the model, these models need a significant amount of statistical data, usually spanning at least one week of recorded information. They work best, though, when making short-term forecasts, especially when predicting a few hours ahead of time. It has been observed that ANN-based approaches have limitations, including the possibility of the preparation process becoming stuck in partial minimums, which would impede the achievement of the ideal solution, and the absence of a trustworthy theoretical underpinning for ANN construction

Statistical-Based Method

A number of statistical methods have been documented for the creation of a wind atlas that includes nominal production cycles and wind farms that are both operational and inactive. These methods also include forecasting the annual output, energy consumption, and cost performance of wind hybrid systems, as well as the monthly and yearly production of wind stations. They rely on statistical analysis of data gathered at the study stations about wind direction and speed. These techniques work well for economy-based strategies, but they cannot forecast hourly wind characteristics.

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As an alternative, several statistical methods for forecasting hourly wind characteristics have been developed. These techniques make use of rational variables and online measurements. They usually use the results of Numerical Weather Prediction (NWP), particularly for long-term forecasts that are prone to errors.

Monte Carlo-based Methods

There are two methods based are given below:

- Using the Rayleigh distribution to determine the wind speeds for each wind powerhouse through Monte Carlo simulation
- Modifying each wind farm's average wind speed based on the incoming wind speed.
- Standardizing the data to produce a collection of standardized uncorrelated variables by dividing the findings by the standard deviation.
- Using the covariance matrix and mean values along with the correlation matrix to derive new values.

The second approach is based on modelling the set of wind speed while taking the previously obtained the second approach uses the conditional probabilities from the first method to simulate the set of wind speeds. The following are the guidelines for using this method:

- Assuming there are n1 values representing the wind speed in a wind power plant.
- Generating r1 values to simulate speed of the wind for a specific wind power plant.
- Determining the above value and assigning Ur2 to illustrate the wind speed for the wind power plant.
- From the dataset counting the occurrences of Ur1 for the wind powerhouse number 1.
- Generating a random number r2 to emulate the wind speed for wind powerhouse number 2.
- Determining the wind speed values to evaluate the wind speed for wind power plant.
- Occurrences of Ur2 in a dataset for wind powerhouse number 2.
- Repeating this process of wind power plant.

Like the initial approach, the outcomes of this technique adhere to a distribution distinct from the Rayleigh distribution. Moreover, both methodologies assume uniform wind speeds across all turbines within each power plant. The first technique is utilized to model the wind speed during each power plant's construction phase and forecast the likelihood of all active and reactive powers within the power grid illustrated in Figure 14

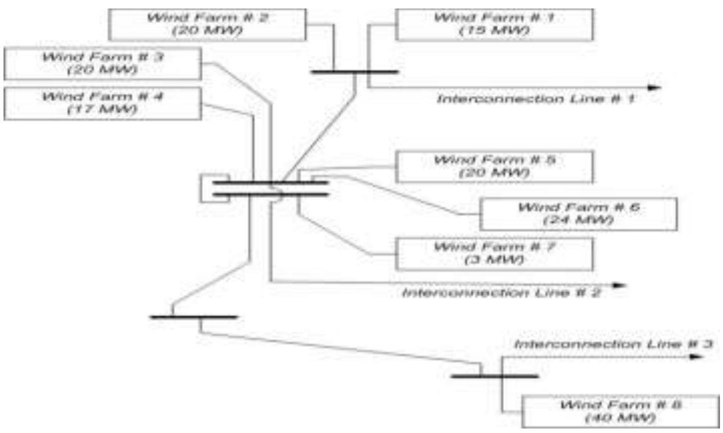


Fig 14. Power grid under study Physical Power Prediction Model

In conclusion, a number of physical models are developed to forecast wind generation over the next 48 hours. These models use Numerical Weather Prediction (NWP) and consider a number of variables, including the location's surface roughness and its variations, the influence of mountain barriers, wind speed fluctuations, the assessment of local wind speed within wind farms, the wind farm's layout, and the power curves of the wind turbines.

Using wind speed forecasts from the Danish Meteorological Institute's High Resolution Limited Area Model (HIRLAM) is required for one of the developed physical models. Using weather traction law,

these forecasts are specially modified for remote locations, guaranteeing their transfer to the surface level for precise evaluation.
Power output of wind power plant following problems:
- Expensive.
- meteorological services are delayed its not certain
- Large errors is producing when there is a temporal replacementamong predicted and actual data.
- Not effective for very short time forecasts.

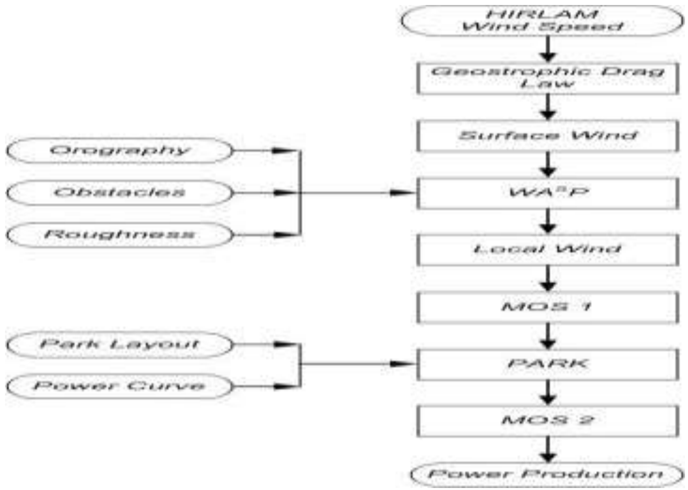

Fig 15. Algorithm of physical forecasting model Conclusions

**Conclusion**
An introductory section on the best places to plant wind turbines inside the infrastructure of the electricity system opens the article The paper then discusses a number of methods for forecasting wind speed and electricity output in wind farms. It then goes into further detail on wind power modelling. The report concludes with a thorough explanation of wind powerhouse modeling techniques, emphasizing the connections between each model

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