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Modeling the available production of wind power plants

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ABSTRACT
Increasing need for energy and limited fossil resources, increasing environmental pollution resulting from the burning of these resources, the effects of global warming and the greenhouse effects, acid rain and the need to balance the propagation of CO2, all call for the necessity of saving fossil resources and increased attention to the use of renewable energy sources. Wind energy is one of the main types of renewable energies that have always attracted the human mind so that man is always thinking of using this energy in the industry. The human had been used wind to move boats and sailing ships and windmills. In the current situation with regard to the above mentioned terms and economic justification of wind energy compared to other energy sources, wind energy seems to be vital and essential. This article firstly provides an introduction to the field installation locations of wind turbines in the power system and then various methods for predicting wind speed and power of wind farms are expressed. After that Modeling of wind powerhouses are explained. Finally, wind powerhouse modeling methods are fully described and the equations of each model are given.

Introduction

For thousands of years humans is using the wind as an energy source. Wind energy, beside the hydropower is one of the most widely consumed types of energy in the seventeenth and eighteenth centuries, respectively. In the late nineteenth century, the first tests were conducted to generate electricity from windmills. Then, in a long period, tend to use wind power declined. Global oil crisis in 1972 led to the large-scale reuse of renewables such as wind power. Currently, wind power is as one of the fixed branches of the electricity market. When installing new wind turbines, energy production is not the only significant criterion; efficiency, cost, environmental impacts and the impacts on the power grid are important issues which are considered when making decisions about new wind turbines to be installed. Political support and public interest in renewable energy has resulted in the emergence of a major increase in the use of wind power which a natural consequence of that is improvement in wind turbine technology. Soon, wind power will provide about 2% of the total electricity needs of Europe (i.e. more than 23,000 MW that 5800 MW is installed in the last year (2002) [1]).

Concerns of the power system

Place of installation of wind turbines in the structure of the power system is constantly changing with a dramatic increase of installed wind power capacity. The wind turbine of 1980s and 1990s were considered as small, local energy sources and had of little importance in the power system. Random nature of wind increases its uncertainty. Therefore, the need to model and predict the impact of wind turbines on the power grid is felt. The dramatic increase in installed wind powers as well as the increasing available plans to use wind power in the future have brought another concern from the power system. Wind power is not considered as a non-significant energy source. The impact of wind turbines on power system stability were always noticed thus, there is a great interest to model and predict the response of wind turbine to transient behavior of power system.

Modelling of wind turbines

Wind turbines are affected by environmental conditions so that these conditions have significant effects on the output load and the useful life and performance of turbine. To achieve more confidence and a higher safety factor for the optimal choice of turbine all environmental parameters must be considered. Environmental conditions are classified into two subgroups of normal and harsh winds. Normal Long-term conditions affect the load on the structure and operation conditions. While although the hurricanes are rare but they can potentially cause critical condition. Wind turbines are grouped in different classes based on their ability to withstand wind conditions in accordance with IEC61400-1 Rev2. Before examining the various methods of pre predicting wind power, we review various models of wind powerhouses [2].

Modeling of Wind Power Plants

In many studies the integrated model is used to simulate wind powerhouses and wind sites, because wind turbines are usually integrated and similar to each other and are connected to the network at one point and basically have the same function. Regarding the use of large wind powerhouses with a large number of wind turbines, integrated model of output power does not have does enough precision, because output power of the wind turbine which uses induction generator and controlled Stall passive, is highly dependent on wind speed changes. In addition velocity at any moment, at different places and for various turbines in a site, which includes a large number of turbines in a distance from each other, has various amounts that can have a of a significance differences.

Meanwhile nowadays another technology is used with the concept of speed variable turbine. In this method Turbines are connected to the network using power electronic converters and controlling the angle of the turbine blades allows the regulation of input power to the generator which is controlled by the blade step angle model and prepares better performance in its nominal

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power and receiving the highest power level from attainable wind energy.

Wind powerhouse model with time varying wind speed consists of the following components:

1. The wind model
2. The models of wind turbine and induction generator
3. The model of capacitor bank
4. The model of the transmission line

The model is shown in Figure 1.

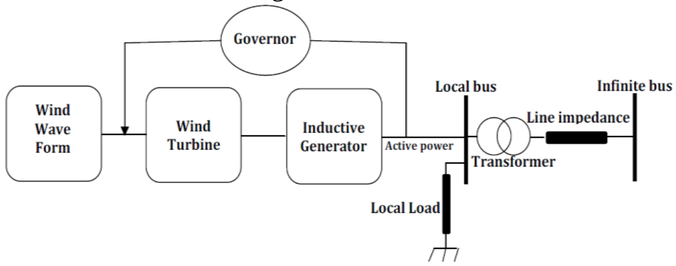

Figure 1. The model of wind turbine

Wind Powerhouse Modeling Techniques

Modelling the wind powerhouse seems necessary in order to check the performance of powerhouse whether it is connected to the network or acts as a standalone system. Modelling these powerhouses helps us to study the performance of wind farms in the natural state use as well as abnormal conditions, such as error conditions, Islanding, voltage fluctuations and changes in the aerodynamic torque. Also, the precise power network modelling with added wind farm is essential to study the impact of these farms on network and dynamic interaction between the network and wind farm. In the past decades, several models have been introduced for wind power houses which are related to the study purpose. Then, the grown models are briefly described [2].

Simple Third Order Model

One of the simplest models is the third-order model which is shown in Figure 2. State variables in this model consist of an induced rotor voltage, the angle of rotor magnetic flux than selected comparison device, and the rotor speed. Mathematical expressions for each induction generator in a power house can be achieved using a rotating reference synchronic frame. This model is different from the conventional model for induction generators which are based on nine state variables, provided by the Cross and also this model does not take into account the stator transient conditions. In addition, these models are grown, the stator voltage and current can be calculated directly from the flux and rotor variables.

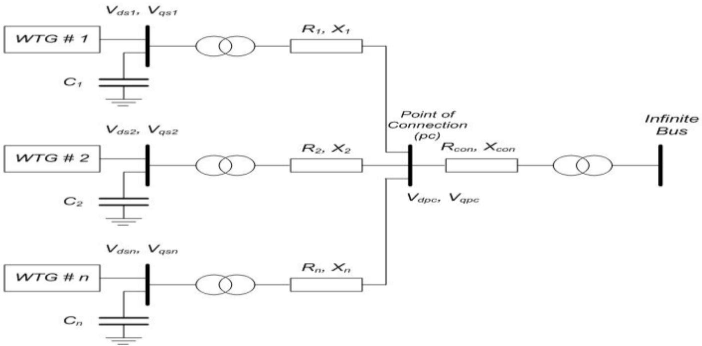

Figure 2. Simple third order model of wind powerhouse

The conjunctions of circuit show that the wind powerhouse is radial. Therefore, the transformations of d and q axis are selected to adjust the capacitors, conjunct the circuits and generators. The fourth order RungeKutta method with 1ms time step is used to solve this model. This model is used for investigating the dynamical performance of 500KW and 1MW wind turbines under various conditions such as sinusoidal fluctuations of operator's torsional torque, voltage disruptions in the network supply and frequency response. Reduced model results were compared with each other. However, the simulation results show the performance of just one wind turbine and not the entire set, indicating that the turbine performance is assumed to be the same. In addition, this model does not include the aerodynamic behavior of wind turbines and the model used for the turbine is only generator model.

PQ and RX Models

Alternatively, another method of modeling wind powerhouse includes considering various amounts for wind speed that leads to different amounts of the active power produced by each generator. In this model, it is assumed that the powerhouse contains N induction motors which are fed from both sides and are parallel connected. First, after the development of model for induction machine fed from both sides, the dynamical performance of the model is tested. Then the active and reactive power of each generator is calculated under various wind conditions. The total active and reactive power of powerhouse is obtained from these calculations, which are shown in figure 3.

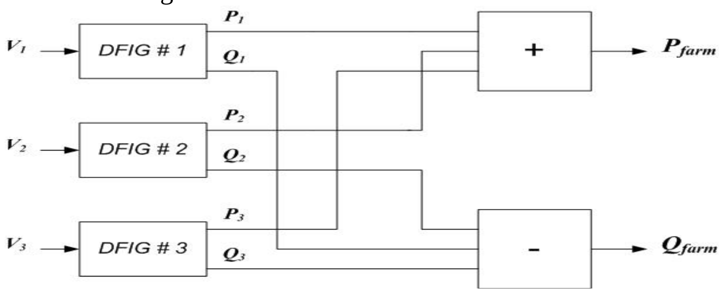

Figure 3. P and Q model for modelling the wind powerhouse

The variation in wind speed in each generator is stimulated in 2 different ways:

1. It is assumed that a constant wind speed with different time varying values is applied to each generator.
2. It is assumed that a sinusoidal wind speed with different frequencies and values is applied to each generator.

In another study, the typical bus PQ model is adjusted for wind powerhouse, where the active power of generator and assumed power index and reactive power of generator are calculated considering the steady state generator model. In this study, generators are inductive and are considered to be the same. Electrical network is illustrated in figure 4 and the model for inductive generators is given in figure 5.

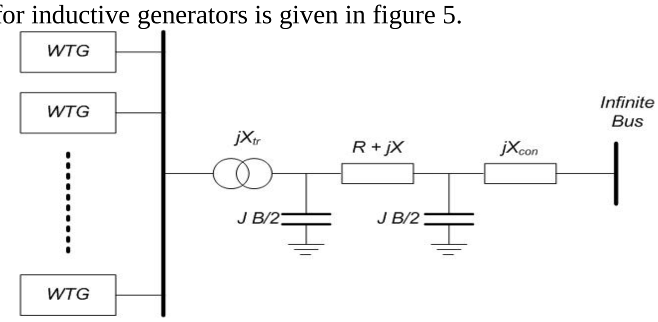

Figure 4. Power System under Study

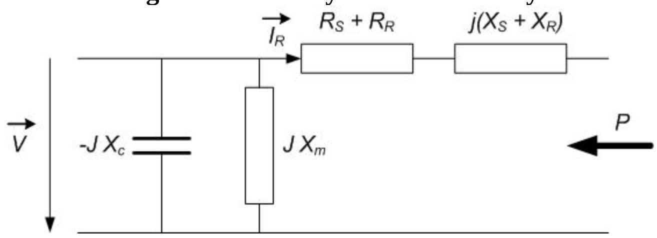

Figure 5. The steady-state model of inductive machine

Here the real power is calculated from power curve in first repetition and the wind speed; then, it is considered to be constant during stimulation. As a result, stimulation is easier, because the reactive power is dependent on bus voltages. Reactive power is calculated by one of these two ways.

1. If the bus voltage is assumed to be constant, then reactive power is fixed and is calculated from the first iteration.

2. If the bus voltage is not constant, then the terms that are proportional to the reactive power and an iterative method are used ¬ (Newton Raphson).

This study presents another model of a wind powerhouse which is based on using the model of RX bus instead of PQ bus. Algorithm of this method is reviewed as followed.

1. An initial value is assumed for machine slide.(usually the nominal value)
2. Impedance is calculated.
3. The wind powerhouse is modeled as a PQ bus which includes Admittance of machines in admittance matrix.
4. The voltages of buses are calculated via first load distribution analysis.
5. The mechanical power of turbines is calculated via $P_m = -I_R^2 R_R ((1-s)/s)$.
6. Turbine tip speed ratio and power factor are calculated, and then the produced power by the wind is calculated.
7. Both powers will be compared with each other. If they were equal, then stimulation is over. If they weren't, the amount of slip will be adjusted by solving the equation, that in this equation, J is a coefficient which depends on machine parameters.

Here are some other assumptions which include:

1. Wind powerhouse consists of two rows of wind turbines, which were separated by large distances not to have interactions.
2. Turbines in each row are so close that their effects on each other are considered.
3. When the wind is blowing perpendicular to the rows of turbines, the wind speed is assumed to be identical for the all machines. If the wind blows parallel, then it is assumed that the wind speed of the first machine in a row facing the wind, and the wind speed for the rest of machines in that row can be approximated.

State Variable Matrix Model

Another model is developed for the study of power system load distribution and transient stability analysis in Cyprus with a small wind powerhouse. Cyprus power grid is simplified with a 690 MW synchronous machine that is shown via rotating in synchronous. This machine shows Node 1, as shown in Figure 6. Loads are shown by$w_i$and are fed by "Z_i+2" impedance along the transmission line. Wind powerhouse consists of 300 kW HAWTs which are equipped with induction generator and are shown by W_{n-2}. Wind powerhouse with impedance Zn is connected to the network. A linear model is used for modeling the wind turbine as shown in Figure 7. (Wind powerhouse density in this model is neglected). A linear model is developed for induction generator using a reference rotating Synchron frame and the general model of system is described as ($\dot{X} = A_1X + A_2MX + BU$) which in the equation: X is the of state variable matrix ($MX = \Delta I_m$) line's flow matrix, A_1 and A_2 are the matrices involving equation of state parameters and U is the control input.

These linear models are efficient for specific operating points. In addition, the same operating conditions are assumed for the turbines which are not realistic conditions for large scale wind powerhouse.

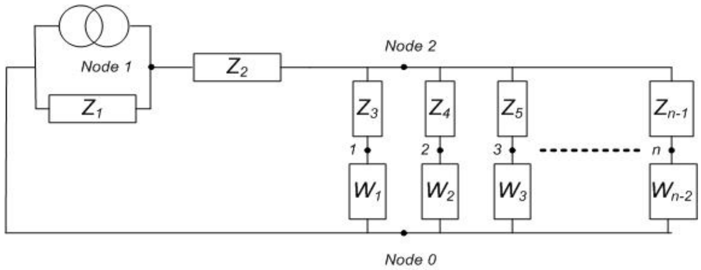

Figure 6. Power system with a connected wind powerhouse

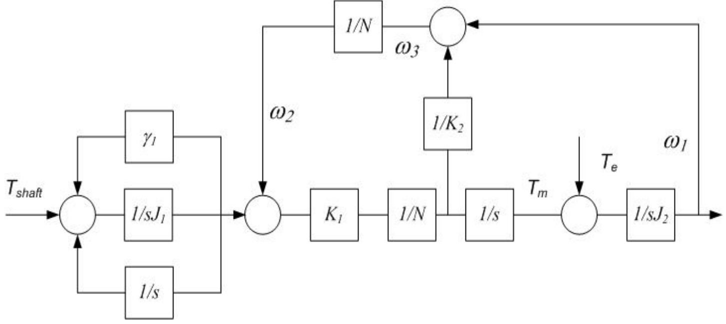

Figure 7. Wind powerhouse dynamics

Aggregated Model

In order to integrate the wind turbines, the model of multiple identical wind turbines (even in the input wind) will combine in a single wind turbine model with a higher nominal power. Parameters are achieved via maintaining electrical and mechanical parameters in the form of perunit and increase in nominal power equal to the turbine available in condensation process. The aggregated model reduces computing time and stimulations in comparison with detailed model by showing tens and hundreds of different turbines and connections. However, the aggregated model requires careful attention in choosing thins aggregating to make it possible to be close to reality. In addition, this type of modeling for wind turbines without a parallel distribution is very difficult (i.e. in the form of an array which is common for wind powerhouses at sea, but not common for offshore wind power).

Detailed Model

One of detailed models is shown in Figure 8 that is for a Danish wind powerhouse including 6 identical wind turbines of equal parameters and working conditions, with a capacity of 2 MW for each turbine and grid-connected. The purpose of this model is to study the impact of power quality such as reactive power, power changes, and wind powerhouse scintillation on Danish power system and under normal operating conditions. This model includes models for grid with connected turbines, models for the mechanical and electrical components of wind turbines, including aerodynamics aspects and the wind speed model. Generators are inductive type.

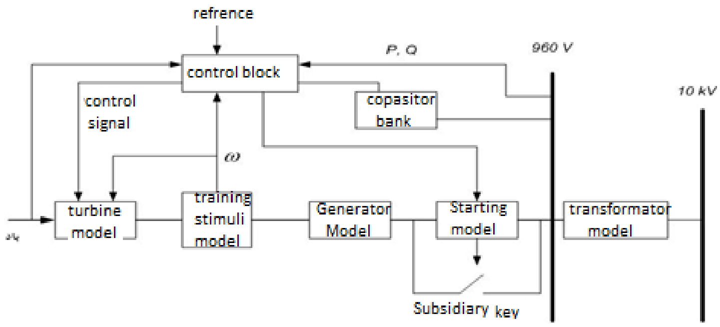

Figure 8. Model of Wind Turbine

Figure 9 shows simplified version of the Block diagram for the electrical model of wind turbine, which includes a control block, stator, capacitor banks, and the transformer.

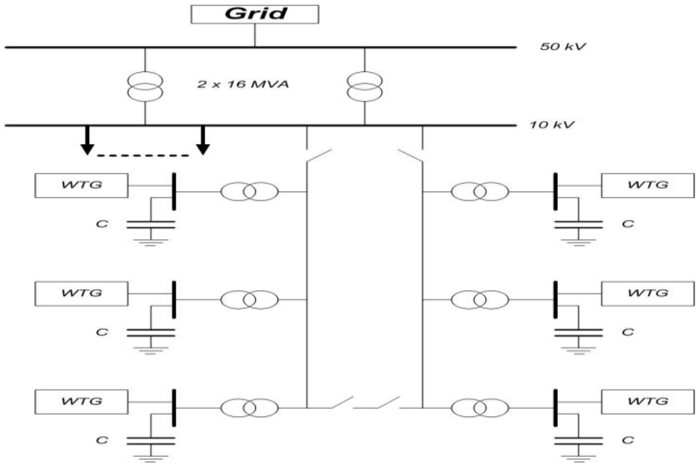

Figure 9. The system studied

Another method is used to evaluate the mechanical systems of wind turbines on power system. Wind powerhouse on the beach under consideration includes 72 identical 2MW wind turbines, arranged in six rows, each row consisting of 12 turbines. The model used to show wind turbine is shown in Fig 10.

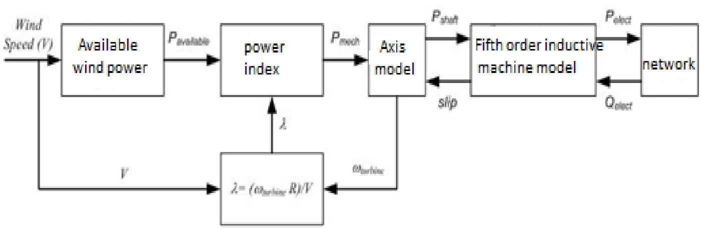

Figure 10. Model of turbines used in detailed model of wind powerhouse

A fifth-order model is used for uncompensated inductive generators which includes the model for the wind turbine shaft. Two hypotheses have been examined individually for windspeed. The first assumption is that there is a regular distribution of wind in wind powerhouse, and that the wind turbines do have the same operating point of 12 m/s. Second assumption is based on the irregular distribution of wind in wind powerhouse which is 14 m/s in places that turbine is exposed to the wind and decreases 0.5 m/s from one group to the other group of turbines in the wind orientation. In the second one the 2 wind orientation is checked: Perpendicular and parallel with respect to the rows of wind turbines. The purpose of this study was to compare the performance of wind turbines and the effect of wind turbine shaft stiffness using different models of wind powerhouses, including the detailed model, the aggregated (multi-machine) and a single machine.

It is worth noting that in large-scale wind powerhouses, the development of such models is very difficult.

Wind speed and power forecasting techniques

Wind speed depends on temperature, pressure gradient and the land type. Prediction of wind is essential to Wind power grid so as to plan to switch on and off wind farms or wind normal generators to the network during operation in order to reduce costs and environmental impact. Also, the prediction of wind speed is determinative to simulate the power output of wind farms and solves the difficulties of determining the distribution of electrical power system's load with generating wind [4].

In this section various methods are given for predicting the wind speed and wind power of wind farms.

Spatial Correlation-Based Methods

These techniques are based on using the collection of data and wind speed from nearby stations to predict wind power and speed in stations under review. One of these methods is based on using a fuzzy expert system (FES) to predict the wind speed and electric power in a wind energy conversion system (WECS). For this method, measurements of wind speed and direction of wind is done in several installed stations around and they are sent to a central computer using a wireless modem in the WECS stations. This central computer executes FES that extracts any space relationship between the measuring stations. In this way, two genetic algorithms are used and are compared with the FES training. Figure 11 shows the FES-based wind forecasting techniques.

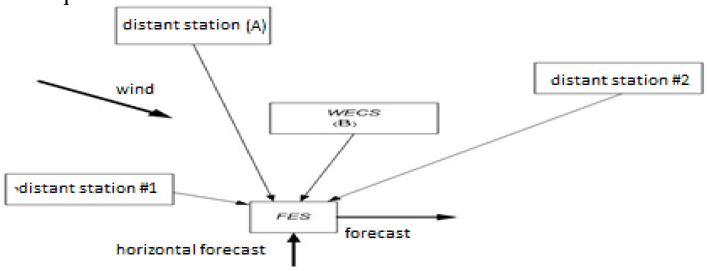

Figure 11. Wind Forecast System

Other methods have been developed to predict the electrical power output and wind speed for a wind energy conversion system in a few hours ahead. This method depends on artificial neural network for the prediction. This method is based on the use of data from multiple locations so that the ANN model is prepared. These measurements are collected from place with distance of of 0.8 km to 40 km.

Recently, advanced techniques based on spatial dependence which use local recurrence neural network and advanced Phased models are developed to predict wind speed and power at least 36 hours.

These models require the collection of information from more than a place to achieve carefully a reasonable and logical prediction. In addition, these techniques are directional dependent. As a result, forecasting wind direction is essential for the correct application of this technique in predicting wind power.

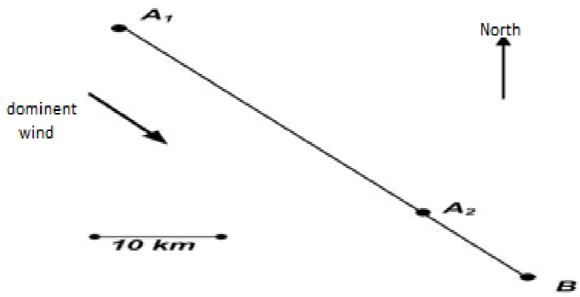

Figure 12. Site with great distances

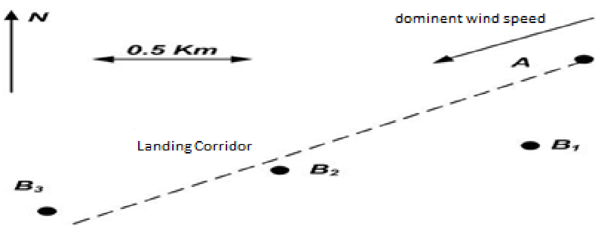

Figure 13. Site with lower distances

Methods Based On Time Series

Various models of time series are provided to forecast wind speeds which include: Auto Regressive models (AR), Auto Regressive Moving Average models (ARMA), Auto Regressive integrated moving average (ARIMA). In addition, the time series models based on the ANN are used to predict wind speeds. Through these models based on ANN, the Elman Recurrent Network (ERN), Adaptive Network-based Fuzzy Inference System (ANFIS), Radial Basis Function network (RBF) and Neural Logical Network (NLN work) are used.

These models require a large collection of statistical information for estimating model parameters and preparation of models (information recorded in at least a week). In addition, these model are effective only for the very short predictions (few limited hours ahead), especially to forecast a step ahead. In addition, it was reported that methods based on ANN have disadvantages such as the lack of a reliable theory of the ANN structure and that the preparation process may fall into the trap in the partial minimum and thus are not able to reach total optimal point.

Statistical-Based Method

Various statistical techniques have been reported for the preparation of a wind atlas, which includes wind farms out of service and the nominal production cycles, of monthly and annual production of wind stations, to prediction of wind hybrid system's performance in their annual production, energy consumption and costs. These techniques depend on statistical analysis of wind speed and its direction, which are recorded at the stations under study. Such methods are effective on economy-based approaches and are not able to predict hourly wind parameters.

Other techniques based on statistics are developed to predict hourly wind parameters. These techniques use online measurement and rational variables. Usually, these methods use NWP output, particularly for long-run forecasts that are often inaccurate.

Monte Carlo-based Methods

There are two methods based on Monte Carlo simulation for the wind speed of wind farms. The first method involves using a series of steps that are summarized below.

1. Using a Monte Carlo simulation to generate wind speeds for each wind powerhouse based on Rayleigh distribution.
2. Reducing the average wind speed for each wind farm from incoming wind speed.
3. Dividing results by standard deviation. These results are in the set of standardized uncorrelated variables.
4. Using the correlation matrix in order to find new values with the covariance matrix and mean values.

The second method depends on simulating the set of wind speed considering the previously received conditional probabilities in the first method. Instruction of this method is as follows:

1. It is assumed that n_1 values exist that shows the wind speed in a wind farm.
2. Production of r_1 values for simulating wind speed for a particular wind powerhouse.
3. Determining the wind speed value U_{r2} in order to illustrate the wind speed for wind powerhouse.
4. Counting the times that U_{r1} appears in a set of data for wind powerhouse number 1.
5. Production of random number r_2 in order to simulate the wind speed for wind powerhouse number 2.
6. Determining the wind speed value in order to illustrate the wind speed for wind powerhouse.
7. Counting the number of times that U_{r2} appears in a set of data for wind powerhouse number 2.
8. Repeat for the rest of Wind Powerhouses

Similar to the first method, this method results are in a different form of duplicate distribution than the Rayleigh distribution. In addition, for both methods, the wind speed for all turbines is assumed to be identical in each powerhouse. The first method is used for the power network of the figure 14 to simulate the wind speed at each powerhouse construction and predict the probability of all active and reactive powers.

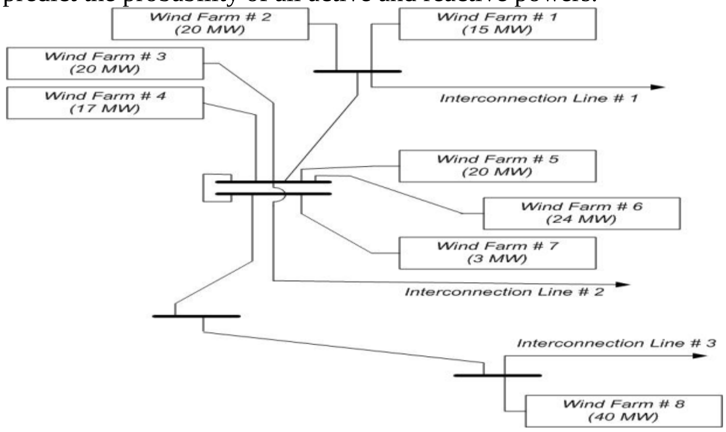

Figure 14. Power grid under study

Physical Power Prediction Model

Finally, several physical models are developed to forecast wind generation for the next 48 hours. These models are based on using the model of Numerical Weather Prediction (NWP) and several factors including surface roughness of location and its changes, effects of barriers of mountains, increase and decrease in speeds, assessing local wind speed in wind farms, the wind farm layout and wind turbine power curves are considered.

One of developed physical models requires using wind speed prediction from High Resolution Limited Area Model (HIRLAM) Danish Meteorological Institute that are especially amended for isolated areas by weather traction law so that these predictions are converted to the surface.

These models are involved in predicting the projected power output of wind powerhouses, but are associated with the following problems:

- Highly sophisticated and expensive.
- When weather services are delayed, are not certain.
- Producing large errors when there is a temporal replacement among predicted and actual data.
- it is not effective for very short time forecasts.
- It depends on the NWP which is often incorrect.

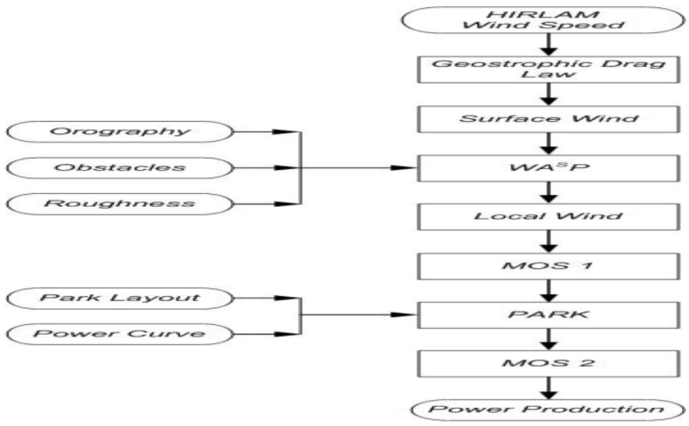

Figure 15. Algorithm of physical forecasting model

Conclusions

In this paper, first an introduction is presented for the location to install the wind turbines in the structure of power system and then various methods are introduced to forecast the wind speed and power of wind farms. After that the Wind power modeling is described. Finally, wind powerhouse modeling methods are fully described and the relationship of each model is expressed.

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Biographies

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