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Quality of Power for Wind Turbines Connected to the Electrical Grid According to International Standards

Ghufran Farhan Marzoog1, Hassan Ali Hameed2, Muhammad Al-Badri3 *, Mansour Farhan4
1Department of Electrical Engineering, University of Wasit, Iraq
2Department of Electrical Engineering, University of Wasit, Iraq
3Department of Electrical Engineering, University of Wasit, Iraq
4Department of Electrical Engineering, University of Wasit, Iraq
**Corresponding author: malbadri@uowasit.edu.iq*

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Abstract:-This article deals with an entrance aimed at giving an overview of wind energy and provides a brief description of the types and designs of wind-turbine horizontal axis. Then this article shows the theoretical study of the flicker of the voltage and harmonics of the electrical current at the wind turbine connection point with the electrical network, according to 21-61400 IEC. In addition, the article presents a report on the tests of the power quality characteristics measurements of a wind turbine with a double-fed induction generator programmatically using the MATLAB program.

Keywords: Wind Energy; Wind-Turbine Horizontal Axis; Power Quality; Double-Fed Induction Generator.

1. Introduction

The demand for electrical energy generated from renewable energies, especially wind energy, in electrical networks during the past years has increased significantly as a result of concerns about the increasing environmental impact caused by the use of fossil fuels. In addition to, fluctuations in oil and natural gas prices, as well as technological development that have led to raising the reliability of Electric generation from wind turbines. Wind power with large capacities currently reaches 2000 megawatts, which called for the necessity of studying the effects resulting from wind turbines in the electrical network [2].

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The International Electro-technical Commission has developed and released standards such as IEC 61400-21 to accurately test and evaluate the quality power characteristics of grid-connected wind turbines. The power quality characteristics of wind turbines are defined in wind turbines specifications, flicker voltages, harmonics, active control reactive and protections, electrical grid and turbine response. In case of faults in the electrical network, with specifying the necessary time that the wind turbine needs to produce electricity after the fault has passed [2].

2. Wind Turbines Horizontal-Axis [1]

The most widely used wind turbine is the horizontal axis turbine. It is often seen in large-area wind turbine fields. The capacity of these turbines is greater than one megawatt. These turbines convert the kinetic energy of the wind into electrical energy through the rotor, which often consists of three blades. The rotor is connected to the speed multiplier, which in turn transmits motion to the generator Figure (1). The amount of power a wind turbine generates depends on the strength of the wind (it is directly proportional to the density of the air, the area of the blades and the speed of the wind). In order to obtain a large wind speed, the wind turbines are raised to a very high level by iron or concrete towers [1].

The most important parts of a wind turbine horizontal-Axis are:

- ***Gearbox***: The gearbox adjusts the speed of the generator at the required speed. It transfers the speed from the shaft connected to the turbine blades to the shaft connected to the generator.
- ***Generator***: Wind turbines are divided into three types according to the type of generator used. These types are (squirrel cage induction generator, two-phase induction generator, and synchronous generator).
- ***Braking System***: It is one of the safety systems, they contains toothed discs that are used in emergency situations or maintenance work to stop the blades from spinning and at the same time the wind turbine stops.
- ***Control system***: The turbine is controlled by a computer, where it is connected to a number of sensors that give data about wind speed and the condition of the blades on the nacelle. The collecting data determine the

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direction of the turbine and the pitch angle of the blades to obtain maximum energy extracted from wind. The best speed and the best energy production [1].

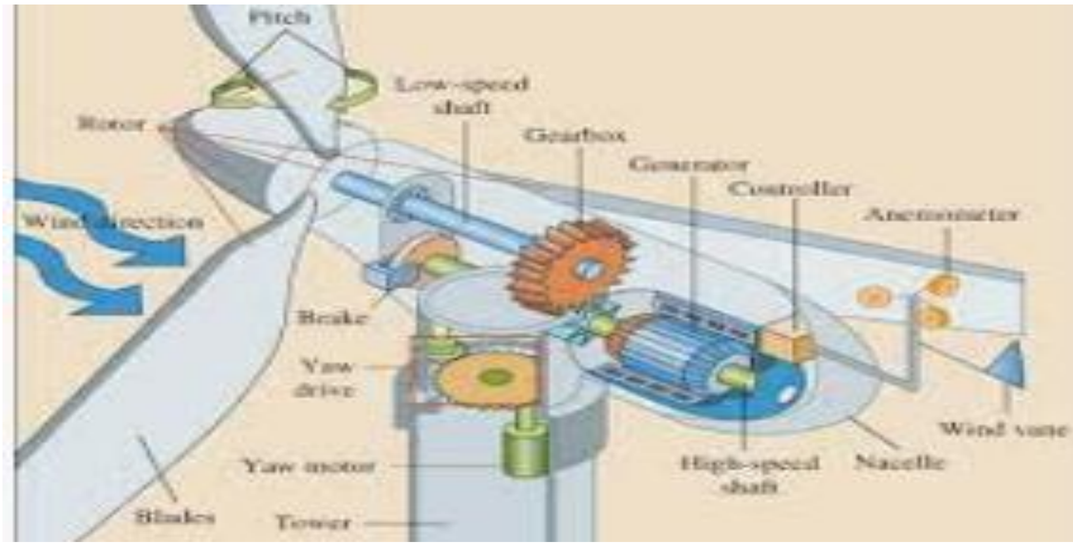

Figure 1 Horizontal-Axis Wind Turbine [Photo - Wikimedia / Enrique Danes].

3. Wind turbine voltage disturbance measurement procedures and evaluation method

First of all, it is important to know that IEC 21-61400 performs its tests in strong networks which consider that the range of short circuit ratio ranges from 20 to 50. Whereas the strong grid imposes on the wind turbine output a certain sine wave, which is loaded with disturbances and harmonics imposed by the electrical grid. Therefore, IEC 21-61400 adopted an evaluation method by means of the phantom network Figure 2, which aims to cancel all disturbances and influences coming from the electrical network by generating an ideal sine wave that simulates the voltage of the electrical network. This sine wave should be the same phase difference between the measured current and voltage of the wind turbine and connect it with the current source that simulates a wind turbine. This connection is based on four different values of the Imaginary inductance and resistance *(Rfic, Lfic)*, meaning four different angles Ψ (30˚, 50˚, 70˚, 85˚) of the network impedance. Subsequently, calculating the imaginary network voltages υic(t), representing the wind turbine voltage, this is the voltage that cancels all external disturbances

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and keeps the peak change similar to the peak change in the wind turbine voltage. So the objective of the phantom network is to study the wind turbine as if it were the only source of voltage fluctuations [1].

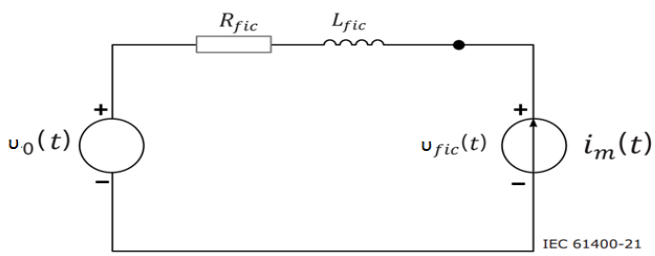

Figure 2 Simulation network for wind turbine voltage [3]

a. Continuous Operation of Wind Turbine

Flicker Measurement calculates the imaginary network voltage according to the relationship:

$$u_{fic}(t) = u_0(t) + R_{fic}(t) \times i_m(t) + L_{fic} \times \frac{di_m(t)}{dt} \quad (1)$$

This voltage is then used as input to the algorithm to calculate the short-term voltage flicker emission Pst, fic value of the phantom network described in reference [4], and this value depends on both the short-circuit power of the phantom network and the phase angle of the network impedance according to the relationship.

$$P_{st,\,fic} = c(\Psi_K)\frac{s_n}{s_{K,\,fic}}$$
` (2)

Where *Sn* is the nominal apparent power of the wind turbine, and $(\Psi_K)$is the flicker factor, which is calculated for four coupling angles as mentioned earlier. Finally, the product flicker value of the wind turbine voltage on the grid is obtained by the relationship:

$$P_{st} = c(\Psi_K)\frac{s_n}{s_K}$$
(3)

It is noticed from this relationship that the value of the voltage flicker is affected by the value of the apparent power of the short circuit *Sk* at the point of common coupling of the wind turbine with the electrical network.

b. Switching operation - voltage change factor and flicker step factor

The effective values of voltages, currents and real and passive power according to IEC - 61400-21 IE are measured by disconnecting and connecting the wind turbine from the electric grid at both the initial and nominal (cut-in wind speed). The voltage change coefficient is calculated according to the following relationship:

$$K_u(\Psi_K) = \sqrt{3} \times \frac{u_{fic,\,max} - u_{fic,\,min}}{u_n} \times \frac{S_{K,\,fic}}{S_n}$$

(4)

Where $K_u(\Psi_K)$ represents the voltage change factor, $u_n, u_{fic,\,max}, u_{fic,\,min}$ represents the maximum, minimum, and nominal effective voltages of the simulated network voltage, respectively. The flicker step coefficient for voltage is also calculated from the relationship:

$$K_f(\Psi_K) = \frac{1}{130} \times \frac{S_{K,\,fic}}{S_n} \times P_{st,\,fic} \times T_p^{0.31}$$

(5)

Where $K_f(\Psi_K)$represents the flash step factor, and $T_p$represents the time period of the wind turbine connection process with the distributed electrical grid of transient disturbances at the moment of connection. The relative voltage change "d" as a result of the wind turbine connection and disconnection operations is calculated from the relationship:

$$d = 100 \times K_u(\Psi_K) \times \frac{S_n}{S_K}$$

(6)

The produced flicker of a wind turbine during these processes is also calculated from the relationship:

$$P_{st} = 18 \times N_{10m}^{0.31} \times K_f(\Psi_K) \times \frac{S_n}{S_K}$$

(7)

Where N_{10m} represent the maximum number of connection and disconnection operations for the wind turbine at the initial wind speed to generate electricity from the wind turbine.

4. Results of energy quality measurements for wind turbines

This study was based on the simulation and modeling program Matlab. The hypothetical wind farm consists of six double-fed induction generators with an apparent power of 9 MVA, four squirrel-cage induction generators with an apparent power of 6 MVA, and a wind turbine with a double-fed generator with an apparent power of 2 MVA, which is the turbine studied in Figure 3. In addition to, the nominal voltage between the two phases of the wind turbine at the connection point with the network is 575 volts at the nominal frequency of 60 Hz, and the apparent power of the short circuit is 56 MVA. All samples were taken from the instantaneous currents and voltages of the studied wind farm at a rate of 10 kHz [5].

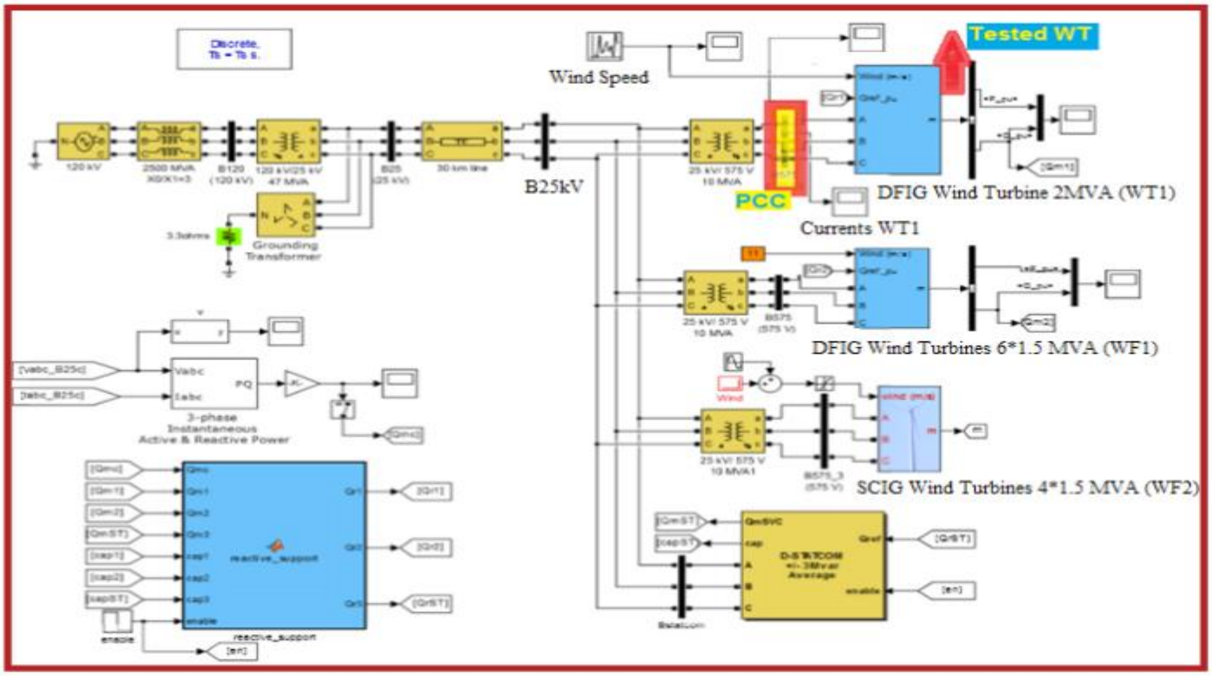

Figure 3 a presumptive wind farm for modeling using MATLAB [5]

Figure 4 shows the values of the coefficient of voltage flicker of the wind turbine WT1 as a function of the ratios of the measured real power to the nominal power of the turbine for the connection angles with the electrical network.

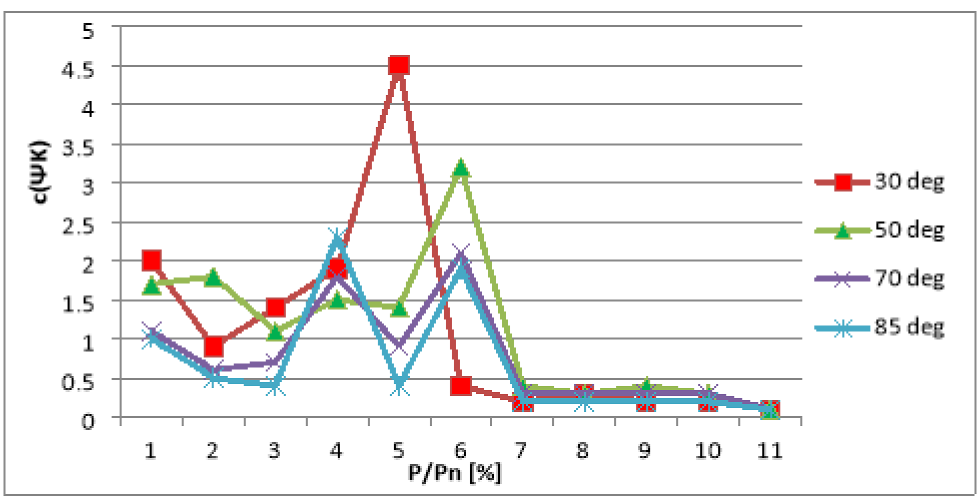

Figure 4 Voltage flicker coefficients [5]

Note from Figure 4 that the values of the flicker coefficients range from 0.13 to 4.1, which are practically acceptable values because it is a simple calculation according to equation (3). They produce voltage flicker between 0.06 and 0.15, which are values less than the maximum permissible value of produced flicker 0.35 according to the technical rules for connecting wind turbines with electrical networks.

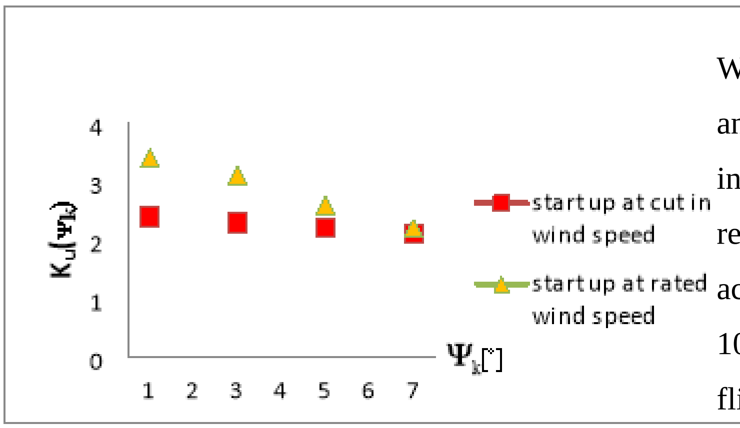

Figure 5 Voltage change coefficients [5]

Figures 5 and 6 shows the values of the voltage change coefficients and the values of the flicker step coefficients when connecting the wind turbine with the simulated network through the four connection angles.

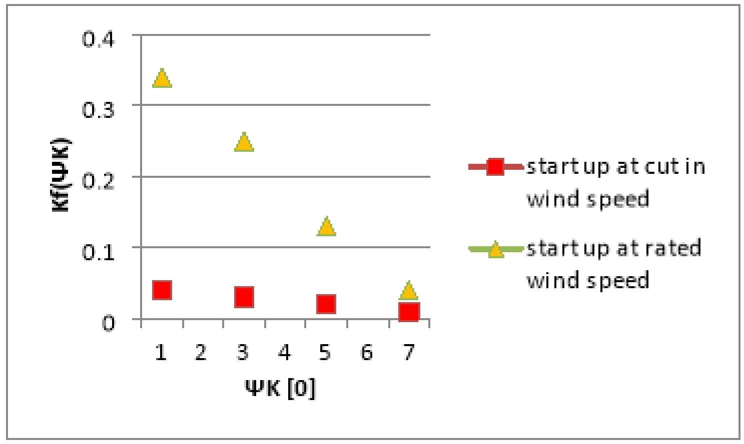

Figure 6 Voltage Flicker step coefficients [5]

With a simple calculation from equations (5) and (6), when a wind turbine takes off at an initial wind speed, the maximum value of the relative voltage change, which is 58.9%, is an acceptable value because it is less than 10%.Also, the maximum value of the voltage flicker is 023.0 which is an acceptable value because it is less than 35.0. Whereas, when the turbine was taking off at the nominal wind speed, the maximum value of the relative voltage change was 56, which is a value rejected according to IEC 61400-21. While the maximum value of the voltage flicker was 20.0 which is acceptable values.

5. Conclusion

It is concluded from this research that the effect of the nature of the traditional electrical network at the wind turbine connection point is the failure to achieve some of the power quality parameters allowed by IEC 61400-21. This resulted in no control tests for both the passive and active power of the wind turbines. One of the most important suggested steps that can be taken in this regard is the (Re-powering) concept of installing modern wind turbines in the sites of old projects where the life span of the installed wind turbines is nearing completion.

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